Project

Climate change vulnerability in the agricultural sector in Latin America and the Caribbean

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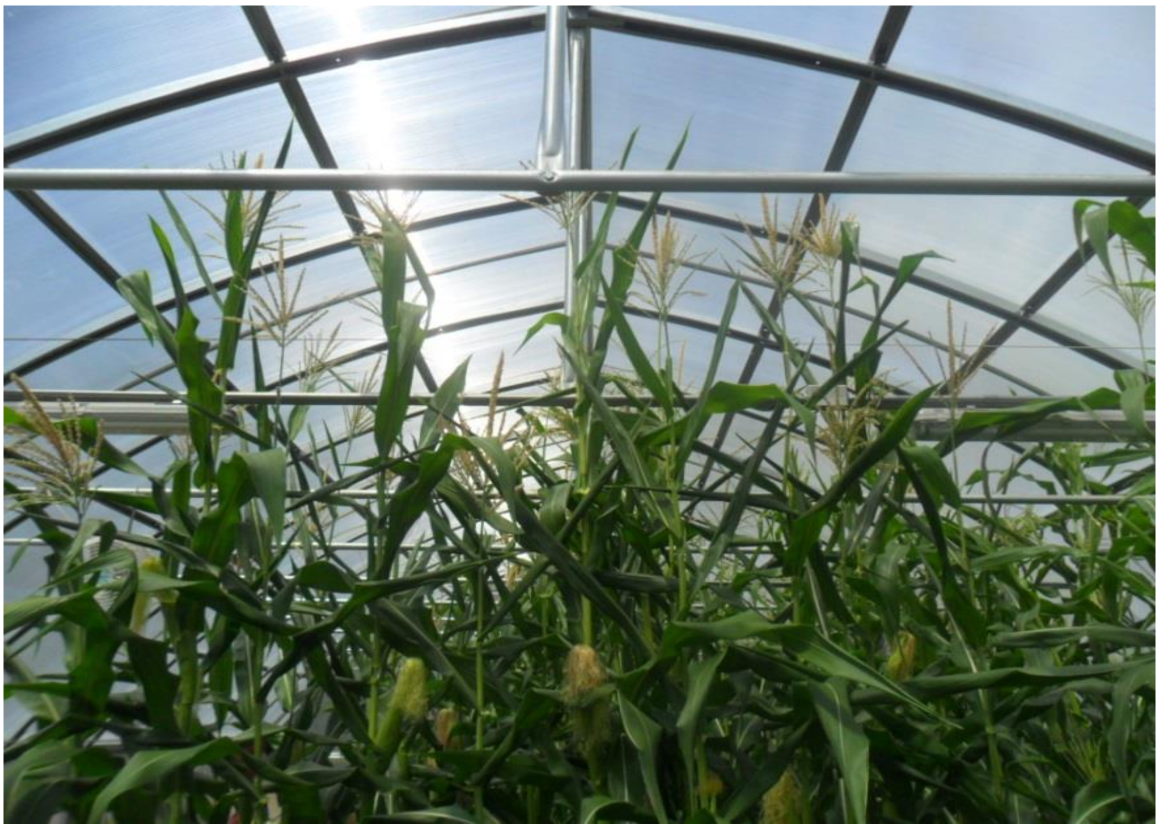

FINAL REPORT:

Modeling Economic Impact of Climate Change in LAC using IMPACT

International Center for Tropical Agriculture (CIAT)

Final Version – July 2016

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1 Purpose of the Study

The purpose of this study is to help inform policy associated with national-scale agriculture investment decisions through better understanding of the potential economic effects of climate change on agriculture in Latin America and the Caribbean. Using a lens of five crops, that both serve as important household staples as well as key economic crops in much of LAC, this report examines how climate change may affect the economic viability of agricultural production through changes in factors such as productivity, harvested area, trade, and food security.

This study uses the IMPACT model developed by the International Food Policy Research Institute (IFPRI) to evaluate the economic impact of climate change as a function of changes in a large number of interacting factors including elements such as changes in marginal revenues, net prices, decisions regarding area harvested, and exogenous influences on productivity (Rosegrant, Msangi, et al. 2008). Uncertainty of climate change is considered through an examination of climate shocks associated with nine different climate models. Though the combination of multiple climate models adds complexity to the analysis and to its interpretation, the multiple models offer the reader a deeper perspective on the range of climate challenges that will be faced by countries in Latin America and the Caribbean as well as the region as a whole.

When examining climate change in the context of agriculture, it is readily obvious that intra- and interregional connectivity are increasingly important to assure an adequate food supply (MacDonald 2013). The effects of climate change dynamics on food production are complex and it is often unclear not only how climate change will affect production but how, in turn, these changes in production have the potential to affect food security. This study investigates this relationship in Latin American and the Caribbean with the idea of better understanding where climate change has the potential to improve the economic situation, where climate change has the potential to exacerbate existing challenges, and where climate change may potentially offset non-agricultural economic improvement derived from elsewhere in the economic system.

2 Introduction and background

Understanding a range of potential pathways regarding the economic impact of climate changes serves as foresight that allows for the development of investment and policy strategies to prepare for the potential future shocks based on plausible scenarios.

In Latin America and the Caribbean (LAC), for example, research suggests that nearly all countries may experience declines in maize yields by 2055 due to expected changes in climate (Jones and Thornton 2003). Given that crop yields are a primary determinant of crop production, climate change thus has the potential to directly affect food security through affecting access, availability, quality and price stability of commodity food crops as well as the prices of the required inputs (Schmidhuber and Tubiello 2007). Additionally, in relation to food prices, Nelson et al. (2009) indicates that climate change impact on yields could increase prices of rice (32% to 37%), maize (52% to 55%), wheat (94% to 111%), and soybeans (11% to 14%).

As the potential economic impacts of climate change on agriculture are linked to a large number of variables with geographic components (e.g., estimates of population growth, timing of the agriculture seasons, crop mega-environments, soils, types of inputs required, distance and access to markets, etc.), it is necessary to evaluate these impacts in both spatially explicit and crop-specific terms. To better understand the potential impact of climate change in LAC we examine five important economic crops in the region alongside approximately 50 other commodities modeled in IMPACT. The crops, including dry beans, maize, rice, soybean and wheat, serve as important commodities supporting both economic activity and food security. As the Food and Agriculture Organization data indicates (See Figure 1), collectively, these crops are of increasing importance in LAC, especially in South America and the Caribbean, with steady declines in contribution to overall gross production value in Central America. Though shares of gross production value have clear trends over time, (downward in the case of Central America), they have also been subject to a great deal of variability as a function of local and international market pressures, prices of inputs, and differences in intensification versus extensification, and climate among other factors (Ruttan 2002).

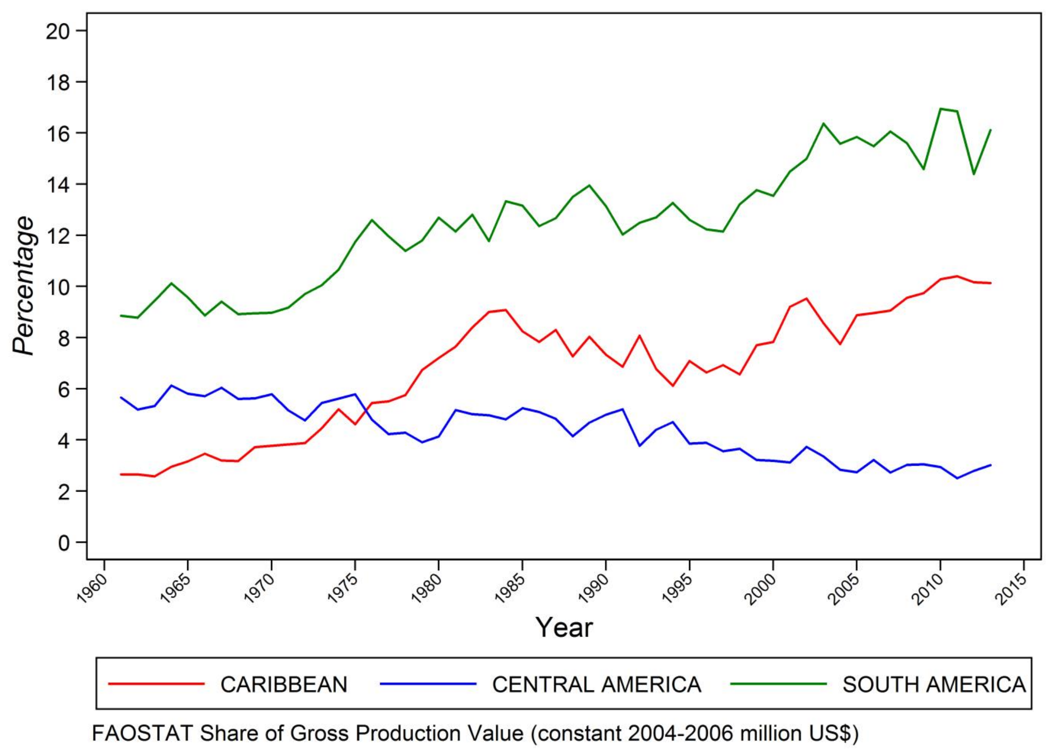


Figure 1: FAO trends in share of gross production value for dry bean, maize, rice, soy and wheat in LAC. Source: Authors from FAOStat data, accessed March 7, 2016.

From a historical lens, it is relatively straight forward to evaluate past agricultural trends, find correlations, and to begin developing insight regarding potential cause and effect relationships related to agricultural production and food security. Looking forward, however, is much more difficult as the benefits of future agriculture technologies are difficult to predict (Rosegrant et al. 2014), and both climate variability and change will influence agriculture production and stability of agriculture commodity prices (Wheeler and von Braun 2013).

To contextualize the potential effects of climate change on the agriculture economy, the theme of food security serves as a useful lens. Food security, was formalized at the World Food Summit in 1996 as, “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life,” (Pinstrup-Andersen 2009). As Pinstrup-Anderson (2009) illustrates, however, food security is complex to measure and given the nutritional and preferential components of the definition, food security cannot be separated from access to clean water, good sanitation, and an adequately varied set of food choices. In examining food security from a macroeconomic perspective, indicators are necessarily much less anthropometric and tend to emphasize the commonly cited dimensions of access and accessibility, specifically food availability as articulated through calories available generated by supply and demand relations and trade, and food accessibility as articulated through changes in prices (Gregory, Ingram, and Brklacich 2005). Though this is a somewhat incomplete picture of food security, the use of the global, sector-specific, partial-equilibrium IMPACT model developed by IFPRI (Rosegrant, Msangi, et al. 2008) allows for reasonable estimates of kilocalories per capita and, ultimately, the relative availability of food and the share of people at risk for hunger (Rosegrant et al. 2014). Given the regional and macroeconomic emphases of this study, the focus is on national scale indicators that serve as a proxy for food availability (Barrett 2010), and to a lesser degree food access as a function of prices and income (Gregory, Ingram, and Brklacich 2005).

In order to facilitate the use of the IMPACT model, the analysis in this study is developed from the lowest level of geography in the IMPACT model known “food production unit” (FPU) up to the regional scale. FPUs are the intersection between global-scale hydrological basins and national boundaries. The principle purpose of the FPU is to serve as a link between the IMPACT economic model and the IMPACT water model. Climate shocks are initially evaluated at the FPU level (simulating local impact based on local conditions, including consideration of input prices in via the yield functions), then economic activity is aggregated to the country level for purposes of facilitating entry into a simulated global commodities market. It is useful to understand the relationship of the model to the different scales at which results can be reported. Figure 2 illustrates the geographical structure of the analysis with each FPU assigned to an analytic region. The analytic regions include Mexico (MEX), Central (CEN - Central America and the Caribbean), Brazil (BRA – the Guianas, and Brazil), Andean (AND – Colombia, Venezuela, Bolivia, and Peru), and the Southern (SUR – the southern cone countries).

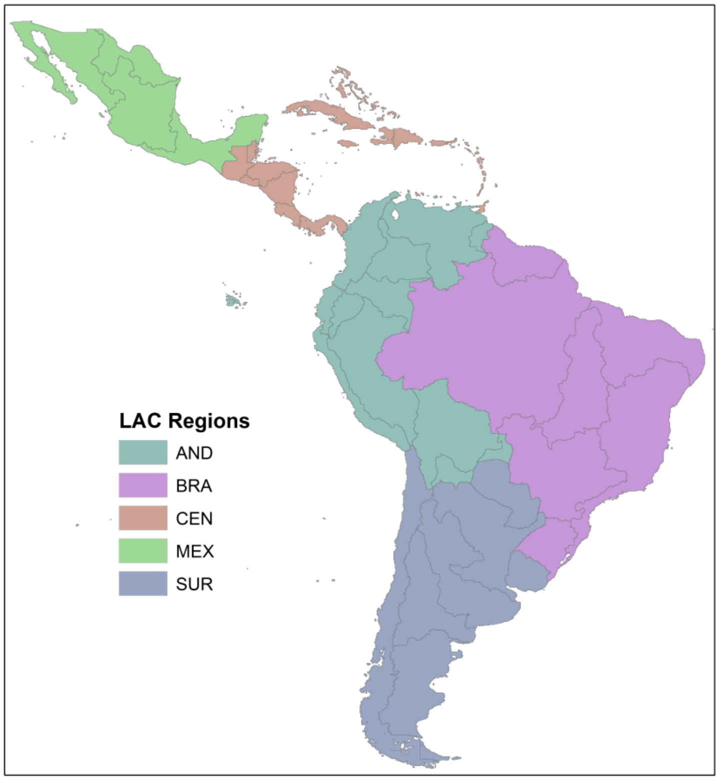
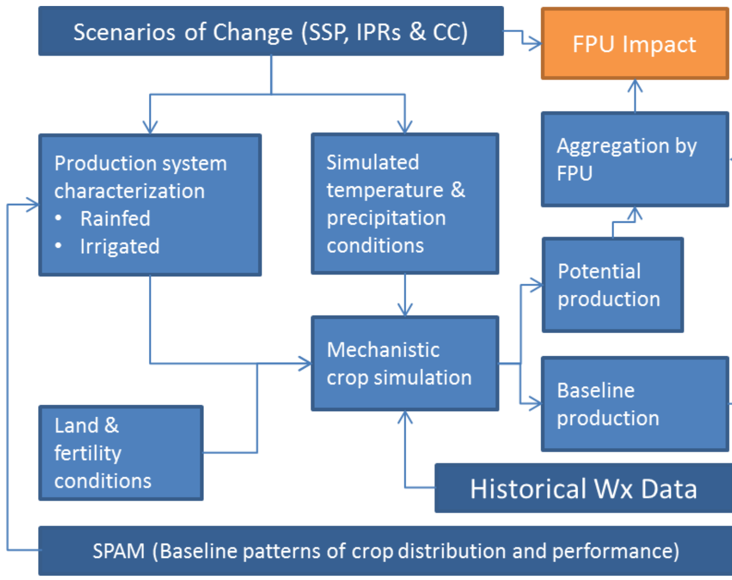


Figure 2: The sub-regions with individual food production unit boundaries highlighted within each region. Note that the regions for the economic analysis differ slightly than those used in the climate change report (Gourdji et al. 2015) due to aggregation within the IMPACT model.

The large number of FPUs, multiple sub-regions, the use of multiple climate models, the global nature of the IMPACT model itself and, finally, the five crops being modeled, result in a complex, multidimensional problem. The reporting of the results is thus complex and requires articulation of the model process and a corresponding contextualization of the results. It should be noted that the IMPACT model aggregates French Guiana, Guyana, and Suriname into a single unit for country-scale calculations and three FPUs whose boundaries are consistent with the country level boundaries. As such, the three countries enter the modeled global marketplace as a single aggregate, with agricultural activity and yield impacts being generated at the FPU (hence, national) level. Given the complex relationships and required aggregations, the following sections characterize how the IMPACT model is used, as well as how the crop by sub-region results can be interpreted as well as the overarching results in relation to the food security of the LAC region as a whole.

2.1 Summary of modeling process

This study and its findings are based on a combination of model outputs and the related modeling workflow. The modeling activities required to realize this study included the use of existing climate modeling results provided by the CMIP project (Taylor, Stouffer, and Meehl 2011), the implementation of downscaling and bias correction approaches to generate realistic temperature and precipitation patterns for the global general circulation climate models, the implementation of crop models to estimate crop yields for both benchmark and future periods, as well as the ex-ante economic modeling previously highlighted (see Figure 3). The CMIP project was designed to generate a consistent basis for understanding the skill of current climate models in simulation both recent past conditions as well as their consistency in projecting future climate scenarios (Watterson, Bathols, and Heady 2013). The regionally appropriate methods used to generate pixel-level climate and weather information for crop models, as well as the crop modeling process itself, is addressed in Gourdji et al. (2015).



Source: Authors, adapted from (Rosegrant et al. 2014).

Figure 3: Modeling workflow for evaluating impact of climate change on agriculture.

The modeling workflow illustrates how estimates for potential economic impact of climate change are driven by understanding the effects of climate shocks at a level of granularity known as the food production unit or FPU. Results from the previously detailed crop modeling effect serve as the “shocks” to either positively or negatively impact production for each crop and for each FPU. Estimates at the FPU level also take into account a variety of exogenous information. Critical factors affecting the IMPACT model results include the specified development trajectory and the estimates regarding the potential for agricultural development (see Table 1). The described workflow is largely consistent with the standard IMPACT modeling workflow and is highly similar to that as described in Rosegrant et al. (2014). Though different modeling approaches will result in different outcomes, it is important to understand that each modeling effort has the potential to provide new insights into climate change even if the results themselves are different among models (Lampe et al. 2014).

Given that models are the sum of the methods and the inputs used, we characterize these in Table 1.

Table 1: Critical information resources used in the modeling process.

Resource	Definition and Basis
Socioeconomic Scenario	Understanding the economic impact of climate change requires certain assumptions regarding the rate of population growth, the rate of economic development, and the relative distribution of economic development. IMPACT uses the established "Shared Socioeconomic Pathways" (SSPs) and in this effort we implement the SSP2 in order to approximate medium growth rates for population and gross domestic product (Vuuren et al. 2014). SSP2 is considered "middle of the road" scenario, with global population reaching 9.3 billion by 2050 accompanied by a tripling of global GDP in the same time period and is often used as a starting point in examining the economic impact of climate change (Gerald Nelson et al. 2014). SSP2 data can be accessed: https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about#intro.
Intrinsic Productivity Rates	The IMPACT model characterizes the interplay between many different commodity crops in a global market. In order to facilitate estimates of non-price related long-term tendencies with each crop, IFPRI has facilitated the development of a trend factor based on expert knowledge that reflects productivity growth driven by technology improvements, including crop management research, conventional plant breeding, widecrossing and hybridization breeding, and biotechnology and transgenic breeding (Rosegrant, Msangi, et al. 2008). This is the factor that is adjusted by the shocks associated with climate change. Also see (G. C. Nelson et al. 2009) and (Wiebe et al. 2015) for support on how IPRs are derived and used to simulate endogenous aspects of the economy.
Spatial Production Allocation Model	An important resource for estimating where different crops are grown is the Spatial Production Allocation Model. Known as SPAM, this dataset maps production and land use patterns related to the crops modeled in IMPACT (You et al. 2014). Using SPAM serves to limit mechanistic based estimates of yield to areas where a harvest can be reasonably expected, with similar implementations in the present study, Gourdji et al., (2015), Rosegrant et al., (2014), and Takle et al., (2013), among others.
Climate Shocks to Crop Yields	Simulated crop yields were used to generate estimates for the climate shock to yields associated with climate change (Gourdji et al. 2015). This may be either a positive shock or a negative shock and is used to adjust endogenous estimates of yield within the IMPACT model. See Section 2.2.

In order to estimate the impact of climate change on the agricultural economy of LAC as a function of the above and including input and output markets as well as agriculture systems dynamics modeled by IMPACT, the establishment of a plausible counterfactual baseline is required. This baseline consists of two key parts, estimates of past crop yields in a benchmark period as a starting point for agriculture development trends, and a comparator scenario assuming no climate change.

2.2 Building the database and establishing an IMPACT baseline

The plausible counterfactual baseline against which impacts of climate change are evaluated must incorporate reasonable estimates for the both the focal crops in this study (dry beans, maize, rice, soybean and wheat) as well as for the other commodities in IMPACT.

In the report on climate change effects on crop yields in LAC, the procedure for estimating crop yields using DSSAT and aggregating to each FPU is fully explained (Gourdji et al. 2015). As with the crop yield study, one of the challenges in assessing the potential economic impact of climate change is the uncertainty associated with the climate models themselves. For this reason, estimates of exogenous shocks to yield as a function of climate are made against the same nine general circulation models (GCMs) used in the antecedent yield study (Gourdji et al. 2015). These GCMs include BCC-CSM1, BNU_ESM, CCCMA_CANESM2, GFLD_ESM2G, INM-CM4, IPSL-CM5A-LR, MIROC-MIROC5, MPI-ESM-MR, and NCC-NORESM1-M.

The critical difference with the economic analysis in comparison with the previous climate change study, however, is that the IMPACT model is a global model that spans more than 50 different crops and related commodities. Estimates for each of the crops and commodities not modeled in Gourdji et al. (2015) are developed using similar methodologies but with a different subset of climate models. This study thus benefited from the latest version of the IMPACT data generated by IFPRI using the relatively conservative Representative Concentration Pathway 4.5 (RCP4.5) carbon scenario and climate models GFDL_ESM2M, HADGEM2_ES, IPSL_CM5A_LR, and MIROC_ESM_CHEM. Multiple model inter-comparison projects suggest that climate model projections (across various RCP levels and models) are relatively limited in the near term (Rosenzweig et al. 2014; Warszawski et al. 2014) and, as such, differences in yield estimates from model choice will be largely within the range of uncertainty already inherit in the climate and crop models themselves (Osborne, Rose, and Wheeler 2013). The workflow described in Figure 3 ultimately simulates a positive or negative yield shock to the endogenous growth rates within the IMPACT model. For both the set of five crops modeled in this study as well as the balance of the IMPACT commodities, it is this yield shock, not the yields based on crop models using climate model data, which serve to parameterize the IMPACT model. As such, while there may be some effect associated with different climate models in IMPACT and in this study, the range of models used in this study and the antecedent crop modeling study will capture more range in potential variation than in the default IMPACT data.

Data for the economic modeling are initially divided into the same two cohorts as for the crop yield modeling. There is a benchmark period from 1971 to 2000, and a future period from 2020 to 2049 (the IMPACT model run itself ends in 2050). The baseline or business as usual scenario projects economic activity given the factors described in Table 1, using the yields provided by either CIAT or IFPRI depending on location and commodity (see Table 2). In that two sources of crop yield data are used, the one generated during the course of this study, the other generated by IFPRI based on a smaller number and different set of climate models, a data consolidation procedure was required. The data consolidation procedure entailed generating a dataset containing the mean estimates of yield by crop for each FPU based on the four models included in the IFPRI data then, based on Table 2, replacing yield estimates for dry bean, maize, rice, soybean and wheat for each of the LAC FPUs shown in Figure 2.

Table 2: Data sources by geography and source.

	LAC	Rest of World
Study Crops	CIAT	IFPRI
Other IMPACT Commodities	IFPRI	IFPRI

Prior to evaluating the impact of climate change as characterized by the abovementioned models, the non-climate change baseline was calculated. In order to evaluate economic trends associated with the five study crops assuming status quo climate conditions, the IMPACT model was run through 2050 with economic assumptions of the SSP2. In this baseline scenario the changes in yield are attributed only to the exogenous IPRs and the other endogenous drivers in IMPACT.

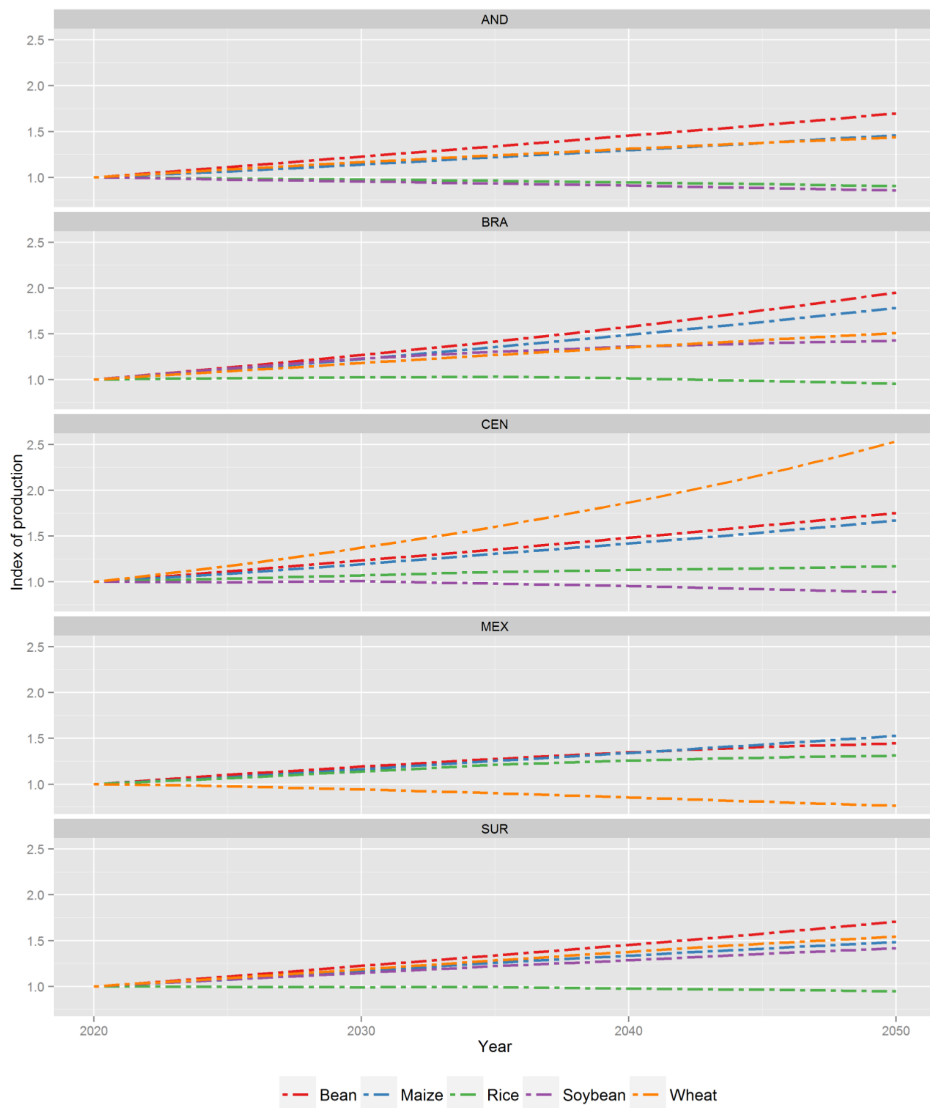


Figure 4: Baseline trends in production without climate change, indexed to 2020. Source: Authors, based on IMPACT results.

Due to population increases and the fundamental role of agriculture in fueling the economy throughout LAC, production for the five study crops is, in general expected to rise. The IMPACT model includes a land market in order to account for competing land uses and potential changes in GHG emission as a function of land use. As Figure 4 illustrates, maize production is expected to increase in each of the sub-regions. For areas in which soy production has been increasing, these trends are expected to continue. Likewise, though dry beans are produced in proportionally lower quantities, the five regions generally show increases through the study period. These non-climate change scenarios illustrate how there is some substitutability for the different commodities and the relative regional importance of each in terms of total production. Maize is important throughout LAC, and the trends without climate change are reasonably consistent with the previously observed increases in yields throughout the region (Figure 1).

While increases in production support both economic activity and access to food, the role of increases or decreases in production in relation to food security is coupled to domestic, regional and international trade (MacDonald 2013). Food security and economic performance more broadly are thus a function of the relationships formed between supply, demand and commodity production and, consequently, the relationship of each producer to the local, regional and global markets. Any shocks that affect production (e.g., reduction or increase in yields due to climate change) will thus propagate their way through the economy and may be exacerbated or buffered by the effects of shocks elsewhere in the system. For this reason, a systems view as facilitated by a model such as IMPACT is useful tool in the development of foresight required for future-oriented policy decisions.

2.3 Understanding impact with IMPACT

The IMPACT model is a partial equilibrium model using a system of linear and non-linear equations designed to approximate supply and demand relationships at a global scale (Rosegrant, Msangi, et al. 2008). The model is flexible and modular and, therefore, allows for the integration of customized data and selection of sub-models in order to tailor the analysis. As the model is a partial-equilibrium model specifically addressing the agricultural sector, transitions between different sectors of economic activity are not considered as in multi-sectoral models (Warszawski et al. 2014).

For this study, the economic impacts of climate change are realized through the standard IMPACT model, less the IMPACT-Water module. The IMPACT-Water model is excluded from the analysis as IMPACT-Water is principally intended to support water stress modeling in hydrological basins reliant on groundwater and is less relevant in tropical rainfed systems (Rosegrant et al. 2005). Furthermore, as IMPACT-Water does not interact with the crop modeling itself and, likewise, is not run for the climate models used in this study, excluding the water module serves to make the modeling simpler and more consistent across the five crops modeled in this study and the remainder of the IMPACT commodities.

The introduction of climate shocks based on the estimated changes in yields was done through the data generation and consolidation process described in Section 2.2. All of the IMPACT model results thus consider the mediated relationship of the smallest unit of geography (i.e., the FPU) to the global marketplace. This mediated relationship is characterized by demand responses to changes in prices and income with adjustments over time to reflect higher value goods over staples (due to economic growth), expert opinion on supply elasticities and marketing margin, and data-driven estimates for producer and consumer support and taxes and tariffs (Robinson et al. 2015).

Numerous studies have used similar approaches and variations of the approach used in this study (Dube et al. 2013; G Nelson et al. 2010; Rosegrant et al. 2014; Rosenzweig et al. 2014; Takle et al. 2013; Wiebe et al. 2015). As the above discussion of the baseline scenario highlights, the model is based on the assumption that no one model of climate can definitely describe climate change. In addition, as previously mentioned, the climate models are used to generate yield estimates which are then used to characterize yield shocks to the endogenous growth rates for each crop built into the model. Also important is that not all of the commodities in IMPACT are modeling using mechanistic approach used here. Many are modeled indirectly based on type and availability of supporting ancillary data (Robinson et al. 2015).

By incorporating several climate models into the analysis, a range of potential system outcomes can be evaluated. One of the challenges of the large number of models, however, is that it necessitates the generation of economic impact assessments using IMPACT for each climate model. For this reason, model outcomes are reported using the distributions of results based on the collective set of models characterized by box and whisker plots to show the median, the interquartile range around the median, and extreme values. In addition, we use two comparator climate models (CCCMA_CANESM2 of the Canadian Centre for Climate Modelling and Analysis, and IPSL-CM5A-LR of the French Institute Pierre Simon Laplace) representing the modeled extremes for climate effects based on changes in world prices. The choice of the comparator models is otherwise arbitrary and is solely intended to provide an upper and lower limit to support comparison of a small number of trends in the data.

In order to incorporate the shock associated with the effects of climate change on yields, for each of the climate models an exogenous growth rate was calculated for each FPU. The exogenous impact of climate change on each crop by FPU it is calculated using:

$$r_{FPU_i-GCM_j} = \frac{\ln\left(\frac{\bar{Y}^{2022-2045}_{FPU_i-GCM_j}}{\bar{Y}^{1975-1998}_{FPU_i-GCM_j}}\right)}{48}$$

As the above equation illustrates, for each crop, the ratio between the mean yields for the benchmark period and the mean yields for the future period is calculated. This ratio is then divided by the number of years between 1987 (midpoint of the benchmark period) and 2034 (mean of the future period). The trend calculated using this basis is then extrapolated to 2050 in order to complete the data series for the full period modeled in IMPACT. With the incorporation of the climate shock into the IMPACT data, the model can then be run for each of the GCMs in addition to the non-climate change scenario.

Given the complexity of the IMPACT model, the multiple scales of analysis, the exclusion of the water module, and the previously identified nuances of the regional approach, output variables must be chosen considering this context. In this analysis, the focus is on output variables that illustrate both changes in production as well as the corresponding links of those changes to more economic outcomes such as trade and food security. All of the data analyzed in the following sections thus generated by the

IMPACT model itself and measures and indices derived from IMPACT generated data. Table 3 describes the data used from the IMPACT model output, for additional documentation on the variables used here as well as other potential variables, we refer the reader to the IMPACT Technical Description, Version 3 (Robinson et al. 2015).

Table 3: Variables drawn from IMPACT model results.

Variable Name	Definition and Basis
Total production (000 mt)	Crop production in IMPACT is specified sub-nationally with the area and yield functions at the FPU level. This provides the added benefit of smaller geographical units for aggregating climate change results, which can vary significantly from one location to another.
Total demand for commodity	Total domestic demand for a commodity is the sum of household food demand, agricultural intermediate demand (feed, and for process goods), and intermediate demand from other sectors.
Crop yields (mt/ha)	Crop yields are a function of the commodity prices, the prices of inputs, available water, climate, and non-price exogenous trend factors. Note that all consideration of yield relationship to climate and water was considered exogenous to the IMPACT model and the IMPACT-derived calculations for available water were not considered.
Total area (ha)	Crop area is specified as an area demand function with respect to changes in the crop's own price, changes in land cost, and exogenous non-price trends in harvested area. Crop area is the total area planted and harvested within a year.
Net trade (000 mt)	Commodity trade by country is a function of domestic production, domestic demand, and changes in stocks.
Import dependency (000 mt)	Import dependency is a ratio of total imports and total supply commodity. This indicator evaluates the relation between food production capacity and international trade dependence or market exposure).
World prices (2005 USD per mt)	Input and output prices are endogenous in the system of equations for food, and are calibrated to year 2005 commodity prices(World Bank 2000; World Bank 2012). Note that 2005 is the base year for all indexing of prices in the IMPACT model. Constant prices are used by the model to facilitate understanding of when prices increase in real terms.
Producer prices (2005 USD per mt)	In order to calculated producer prices an appropriate wedges are applied to the domestic consumer prices. The price wedges are used to reflect effects of producer support estimates (PSE), consumer support estimates (CSE) and marketing margins (MM) on overall price.

Consumer prices (2005 USD per mt)	Consumer prices are determined different for traded and non-traded commodities. Traded commodities prices are determined in international markets. Non-traded commodities are determined in national markets without direct links to international markets.
Share of population at risk of hunger (%)	From IMPACT documentation (Robinson et al. 2015): "The share at risk is the percentage of the total population that is at risk of suffering from undernourishment. This calculation is based on a strong empirical correlation between the share of undernourished within the total population and the relative availability of food and is adapted from the work done by Fischer et al. in the IIASA World Food System used by IIASA and FAO (Fischer et al. 2005)." The work of Fischer et al. (2005) establishes the "basic linked system" (BLS) that couples world agro-ecological zones with IPCC socioeconomic scenarios in order to estimate supply of calories relative to "national food requirements" that are empirically estimated.
Number of people at risk of hunger (million)	From the adaptation of the Fischer model previously described.
Number of malnourished children (millions)	Malnourished children under the age of five is specified as a function of the average per capita calorie consumption, female access to secondary education, the quality of maternal and child care, and health and sanitation. This is based on an empirical model estimated by Rosegrant (2001). This work is based on the cross-country regression model previously developed by Smith and Haddad (2000), with data coming from standard World Bank Develop Indicators, United Nations and FAO datasets.
Food availability (kcal/person/day)	The resultant kilocalories per capita, aggregated by country. An estimate of the amount of calories obtained from commodities in IMPACT as included in the IMPACT-Food module. The per capita kilocalorie availability is derived from two sources: (1) the amount of calories obtained from commodities included in the IMPACT-Food model and (2) the calories from commodities outside the model (FAO 2015), (Robinson et al., 2015).

While the above list of variables is a partial characterization of the outputs produced by IMPACT, it represents a carefully chosen set of indicators. With these variables the analysis facilitates understanding both how and why climate change may affect the commodity crop economy and, by extension, the relationship of climate shocks to the food security of the region.

3 IMPACT modeling results

Climate change is a global phenomenon and for that reason, IMPACT is similarly a global model. Likewise, as a partial equilibrium model for the agriculture sector, IMPACT commodities span those found in agriculture systems around the world. In that the commodities in different regions tend to be biased towards the climate characteristics and sociocultural preferences of the region, commodities are not necessarily elastic by region and may not perfectly substitutable.

In order to understand the IMPACT model results given the regional specificity associated with Latin America and the Caribbean, the study starts with a global perspective. This global context serves as a backdrop for the dynamics in LAC and offers a basis for understanding if trends in LAC are specific to the region or in keeping with broader global tendencies.

Following from the global perspective, the analysis then proceeds to the five study crops both in the context of the identified sub-regions as well as for the LAC region as a whole. In this section, the study progresses to a more in-depth examination of the crop and regional dynamics as well as a characterization how climate change and uncertainty therewith may differentially affect the sub-regions within LAC.

The analysis concludes with an examination of the interplay between the economic trends and indicators of food security. This final analysis offers perspectives at the national and regional scale on how different countries may fare given expected changes in population pressure, agriculture production and economic development.

3.1 Review of global price-production relationships

Though assumptions regarding prices are particular to the model, IMPACT projections indicate substantial increases in world prices for each of the study crops (see Table 4). The model indicates, almost universally, that prices would increase in association with climate change relative to the baseline scenario for each of the GCMs and crops studied. Globally, wheat is the commodity least affected by changes in price while maize is the commodity most affected. It should be mentioned that the modeled world prices are driven by producer and consumer prices and the effect of the represented consumer and producer subsidy equivalents that, “measure the implicit level of taxation or subsidy borne by producers or consumers relative to world prices and account for the wedge between domestic and world prices,” (Rosegrant, Msangi, et al. 2008). Demand, and thus prices, also reflects different uses associated with the crops (i.e., at a global scale). For example, while dry beans and rice are principally food crops, maize, soy and wheat are “flex crops” (Saturnino Jr. et al. 2012). Crop use, combined with local efficiencies or other economies of scale, thus affects prices and these effects will differentially impact trade at the sub-regional, regional and global level.

Table 4: Percent change in world prices between 2020 and 2050 by crop and climate model.

Crop	bcc_csm1_1	bnu_esm	cccma_canesm2	gfld_esm2g	inm_cm4	ipsl_cm5a_lr	miroc_miroc5	mpi_esm_mr	ncc_noresm1_m	Mean Change	NoCC
Dry bean	7.7	8.9	9.6	9.3	8.3	9.9	8.8	8.5	10.0	9.0	4.6
Maize	42.9	44.0	44.1	43.9	43.0	46.3	43.9	44.0	44.0	44.0	27.6
Rice	26.5	26.8	26.7	26.9	26.5	27.4	26.8	26.7	26.9	26.8	16.1
Soybean	7.7	9.9	2.1	7.2	6.4	11.3	8.3	9.9	8.2	7.9	4.9
Wheat	14.2	14.7	14.4	14.5	13.9	15.7	14.6	14.7	14.5	14.6	11.7

Note: World prices are the values used in the global market for the equilibration of the model.

Large, sustained shifts in prices of commodity crops are thought to signal substantial changes and the potential re-equilibration of supply and demand (Rosegrant et al. 2014). Given that poorer populations typically spend a high percentage of their income on food and that the poor tend to be more exposed to price volatility, changes in price may substantially impact demand (Food and Agriculture Organization of the United Nations (FAO) 2011). World Bank studies have shown that, for the poorest in the region, percent of total expenditures on food can range from 83.3% in Honduras to 32.1% for Brazil (Sennhauser, Torre, and Cord 2014). Common drivers of these shifts include higher demand from population and income growth and/or declines in yields or production due to climate change (Gerald C Nelson et al. 2010). Given that predicted increases in prices, with the exception of wheat, are generally exacerbated by climate change and the yield for each crop are generally expected to decline in LAC (see climate study report), the model suggests that consumers would seek alternative commodities, if possible, as a function of these changes. Nevertheless, the changes in prices have the potential to adversely impact agricultural-specialized households (Hertel, Burke, and Lobell 2010).

The world price, from which the consumer and producer prices are derived, is ultimately the equilibrating mechanism for global supply and demand function of the various commodities. Production, in order to meet demand, is a function of a set of area and yield responses which account for a variety of factors including prices of inputs, area and yield price elasticities, and others (see Appendix for further explanation). The dynamics of production as a function of area and yield response underscore the need for looking at a range of climate scenario and for understanding specific crop-by-region responses to climate change (Table 5).

Table 5: Percent changes in key agriculture variables for the comparator GCMs, 2020 to 2050.

Variable and Region	Dry Bean			Maize			Rice			Soybean			Wheat		
	cccma_canesm2	ipsl_cm5a_lr	NoCC	cccma_canesm2	ipsl_cm5a_lr	NoCC	cccma_canesm2	ipsl_cm5a_lr	NoCC	cccma_canesm2	ipsl_cm5a_lr	NoCC	cccma_canesm2	ipsl_cm5a_lr	NoCC
Production															
AND	45.3	38.9	54.8	18.9	3.3	36.0	-10.8	-20.0	-7.1	31.2	28.9	-11.2	28.9	30.5	36.4
MEX	38.8	44.3	39.4	32.6	22.2	41.4	18.5	13.3	28.4	NA	NA	NA	-33.2	-36.5	-18.2
SUR	143.3	142.6	55.2	47.3	39.2	39.7	3.5	3.2	-3.4	30.1	35.1	34.1	24.3	11.8	44.9
BRA	56.6	56.1	72.0	47.5	38.3	60.1	4.6	1.0	-0.9	52.8	33.2	38.9	24.9	15.8	41.7
CEN	36.6	37.0	58.7	27.6	21.7	51.5	3.9	5.4	14.4	-13.3	-9.2	-7.3	87.9	72.3	110.6
Yields															
AND	19.4	14.7	23.5	12.8	8.1	15.3	-8.7	-10.9	-8.1	2.6	4.2	-5.9	8.5	9.5	12.1
MEX	14.1	17.6	13.8	13.0	10.6	12.3	3.1	2.5	3.9	NA	NA	NA	-26.7	-28.5	-18.7
SUR	44.8	44.8	20.9	33.0	30.0	24.8	-6.0	-6.2	-9.9	16.2	20.4	18.5	10.0	5.8	17.0
BRA	24.2	26.8	31.6	27.7	25.0	28.0	-5.7	-6.9	-9.4	28.2	26.4	26.4	8.2	5.6	13.4
CEN	19.3	20.5	25.6	14.4	13.2	17.2	-2.7	-1.3	0.1	-7.2	-3.8	-5.7	28.4	25.9	33.0
Area harvested															
AND	21.8	21.1	25.4	5.4	-4.4	18.0	-2.3	-10.2	1.0	27.9	23.7	-5.5	18.8	19.3	21.8
MEX	21.6	22.7	22.5	17.3	10.5	25.8	15.0	10.6	23.6	NA	NA	NA	-8.8	-11.3	0.5
SUR	68.0	67.6	28.4	10.8	7.1	12.0	10.1	10.0	7.2	11.9	12.3	13.2	13.0	5.7	23.8
BRA	26.1	23.1	30.6	15.5	10.6	25.1	11.0	8.4	9.4	19.1	5.4	9.9	15.4	9.7	25.0
CEN	14.6	13.7	26.4	11.6	7.5	29.3	6.7	6.8	14.3	-6.5	-5.7	-1.8	46.4	36.8	58.3

*Note that the selected climate models are the climate models that result in the greatest and least magnitude effects of changes in word prices.

In examining Table 5, several preliminary observations stand out. First, according to the model, substantial increases in production are expected in dry bean, maize and soybean. In many instances, however, the increases in production associated with climate change shocks are less than would be expected without the shock. Even without considering climate change, wheat production is expected to decline in the Mexico sub-region (with an 18.2 percent reduction), and the decline is expected to be approximately double that when accounting for climate. Though these findings are somewhat contradictory to earlier estimates by the International Center for the Improvement of Maize and Wheat that suggested small gains in productivity by 2020 (*Global Trends Influencing CIMMYT's Future* 2003), these results use a different version of the IMPACT model, different social scenarios, and different climate scenarios and, as such, are not directly compatible. This underscores the need to interpret the results of this analysis within the context of the analysis itself as different modeling scenarios are not necessarily comparable on a one to one basis.

Without climate change, AND, SUR, and BRA are all expected to see declines in production of rice. Climate change is expected to have a positive shock in the southern cone, likely associated with the warming trends, while the situation is expected to worsen in the Andean region. Soybean also shows expected declines in production in both the Andean and Central region under the no-climate change scenario, while the model suggests climate change will actually improve production of soybean in the Andean region, soybean continues to lose ground in the central region.

Overall, the model results indicate that net trade (trade as a function domestic supply minus domestic demand and considering stocks held) will increase slightly under climate change, principally due to the change in world prices. Regional changes in net trade are driven by sub-regional activity which is examined in the next section. In general terms, however, climate change appears to have a median negative impact on crop yields all over the region with a median reduction across the study crops, sub-regions and GCMs relative to the non-climate change values. These negative impacts on yields are followed by reductions in total area, and production (see Figure 5). Again, these trends are explored in the following sections from the crop by sub-region perspective.

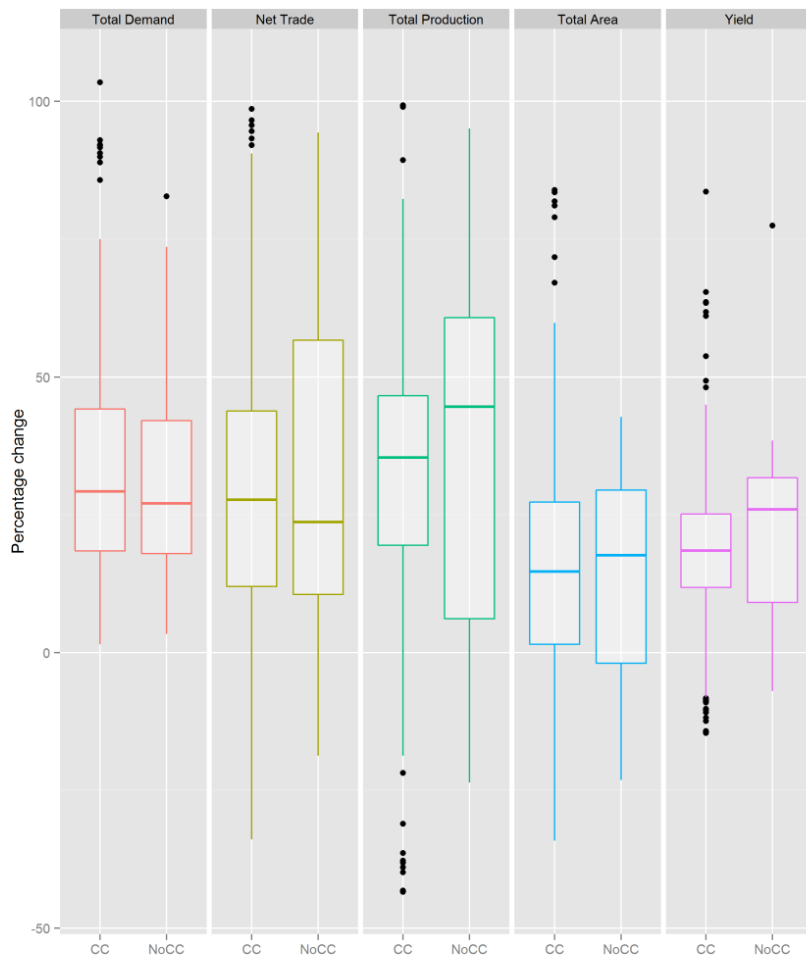


Figure 5: Change in agricultural trade, production, area and yield, with and without climate change, based on the five study crops for the LAC region (% change from 2020 to 2050 for all crops for each FPU). Data shown are between the 1.0% and 94% quantiles to improve readability.

While it is clear that climate change would have the potential to increase prices at the global scale, the effects of climate change vary substantially by crop and by geographic area. Likewise, while a small increase in net trade of the region is expected with climate change, regional changes in net trade, production, harvested area and yield are highly variable. The study highlights a great deal of heterogeneity both sub-regionally and between the crops in question. In the following section this heterogeneity is evaluated on a per-crop and per sub-region basis.

3.2 Sub-Regional analyses by crop

The effects of climate change on key indicators such as production, demand, net trade, area harvested, prices and yields, vary substantially by crop and by sub-region. Variation of crop performance in any given area is a function a variety of factors including, but not limited to, the geography of the region, expected exogenous contributions to the yield drivers, and demand (domestic and international) for the commodity in question. For example, while crop production is negatively affected in some sub-regions, elsewhere the same crops are positively impacted by climate change. As a result, the impact of climate change on total area, production, and prices are crop and sub-regionally specific.

For each crop, the key indicators from the IMPACT model are evaluated. The range of potential impacts to production is evaluated in terms of change in production between 2020 and 2050 relative to the no climate change scenario. In turn, the effect of this change in production is evaluated in relation to its impact on net trade over the same time period.

3.2.1 Dry bean

Dry bean, consisting of any number of varieties of *Phaseolus vulgaris*, or common bean, has a long history as an important source of protein and calories in Latin America and Caribbean. Dry beans are known to be sensitive to climate change, with expectations for increases in both abiotic and biotic stressors associated with changes in environmental conditions (Beebe et al. 2011). In particular, beans tend to be sensitive to heat and drought and this is reflected in predicted declines in production throughout LAC with the exception of SUR, the most temperate region (see Figure 6).

Results suggest that projected reductions in yields, especially in rainfed zones, in AND, BRA, CEN, and MEX may have an important effect on both total production, and area. The projected reductions in yield are the consequence of corresponding decreases in rainfall under the various climate change scenarios, which in turn increases water stress in zones where dry bean is grown under rain fed conditions. Projected reductions in bean production are especially important in AND (-21 percentage points or pp), BRA (-22 pp), and CEN (-24 pp). In addition MEX also will experience a reduction of -5 pp, in comparison to the scenario without climate change.

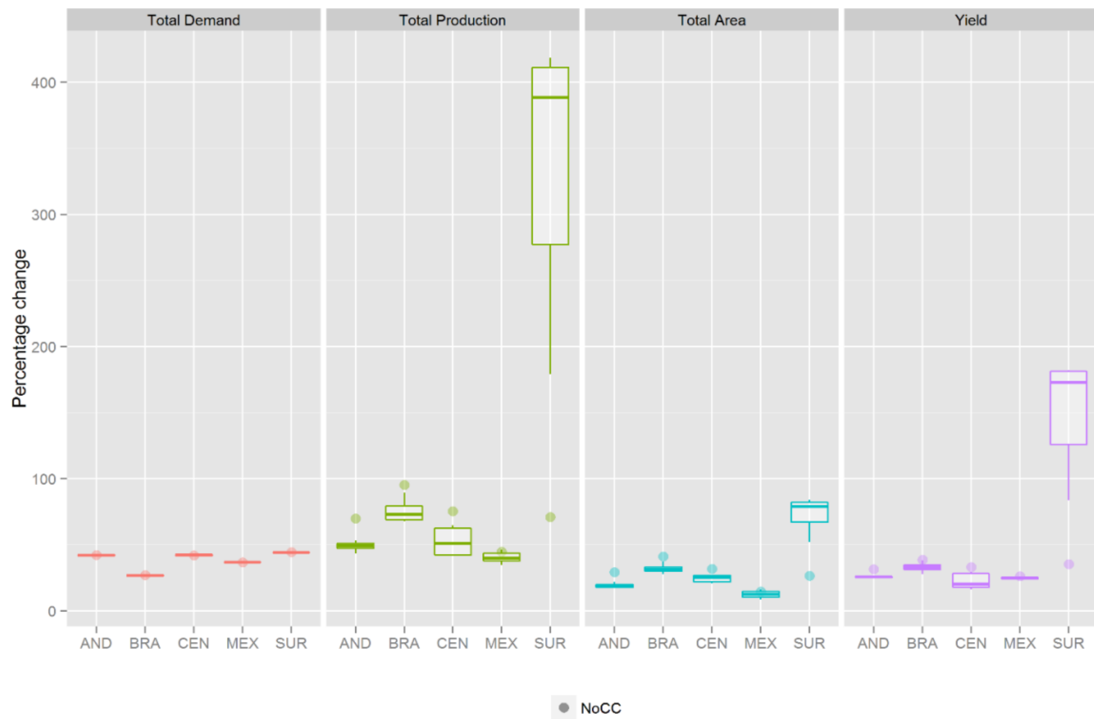


Figure 6: Percent change in key variables for climate change relative to the non CC scenario for beans.

Though declines in production are also expected in the Mexico region (MEX), the observed change is within the range of the predictions associated with different climate models. In contrast to the rest of the LAC region, production is expected to increase in SUR under climate change over the non-climate change scenario. With both economic factors and positive climate shocks driving this increase, the trend is highly consistent among climate models and represents high potential growth in production.

Transitions in net trade reflect both changes in demand and total production. For the case of dry bean, results suggest that since demand is highly inelastic, and while production generally decreases, net trade tends to differ under CC and NoCC scenarios on a sub-regional basis. Under climate change, trade deficit (reductions in trade surplus) is anticipated to grow. On the other hand, in the SUR sub-region, climate change results in a positive shock yield, most likely due to favorable changes in precipitation and temperature in the geographic area associated with bean production. These results suggest that, in relative terms, climate change may positively influence SUR in dry bean commercialization at a LAC scale, while BRA and MEX, the other two important producers in LAC, may exhibit reduction in their trade surplus, respectively (Figure 7).

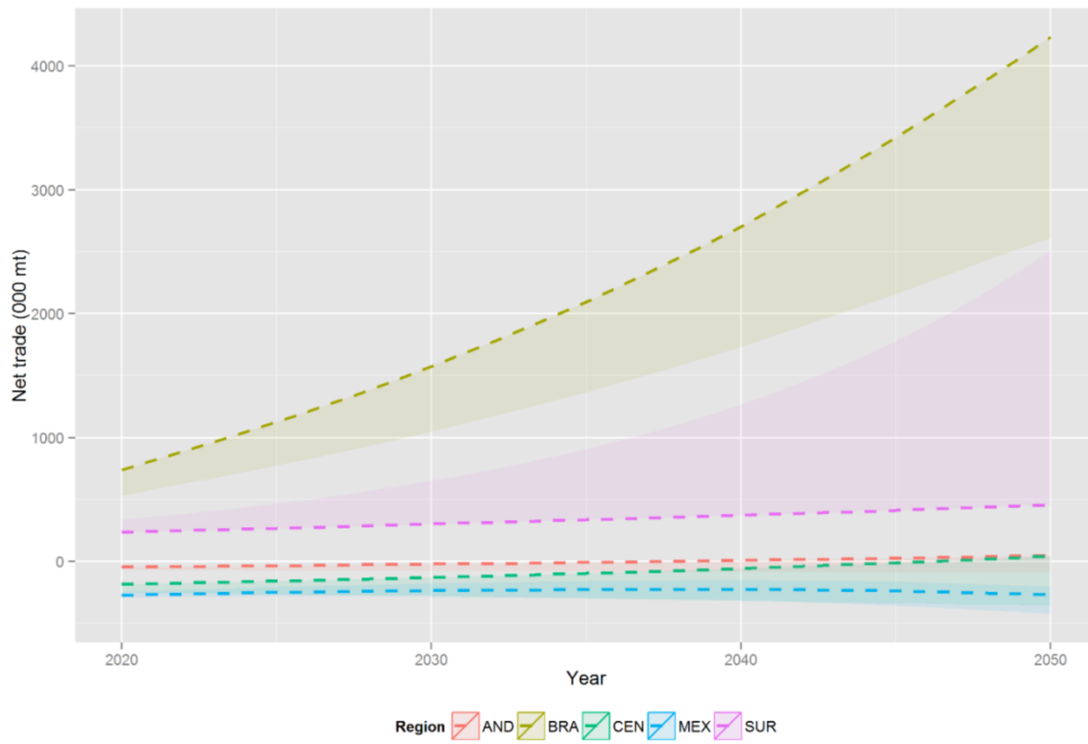


Figure 7: Tendencies for net trade of dry beans showing regional variation across climate change scenarios. The dotted line is change in trade without considering climate change.

Regional sensitivity to the different climate models and corresponding uncertainty associated with the modeling of climate impact is clearly illustrated through the trends in net trade. Besides the mentioned differences among sub-regions, it is also important to highlight that areas where dry bean production may be more negatively affected by climate change (e.g. CEN) are also areas where the crop is currently grown by small farmers (Schmidt et al. 2012). These producers also tend to have less access to inputs such as fertilizer and water for irrigation (Rosas et al. 2000).

The trends in net trade for dry bean illustrate both how the estimates of climate impact are uncertain and a function of the models in question, but also how agreement of trends has the potential to yield new insights even in the face of uncertainty.

3.2.2 Maize

Results from the IMPACT model indicate that climate change may negatively pressure total demand for maize, with downward pressure on maize production in all sub-regions less SUR (Figure 8). Projected declines in maize production under climate change will be the result of both projected declines in yield (observed throughout LAC) as well as changes in the amount of land used to grow maize. Land area under cultivation is expected to increase in both BRA and SUR. The projected declines in maize production under climate change are the result of substantial decreases maize yield, especially under rain fed conditions. As highlighted in the crop model report (Gourdji et al. 2015), rain fed zones in central Mexico, the Yucatan, and northern South America will be all be affected by projected reductions in rain fall. This is consistent with related research where estimates indicate the potential for an approximately 10% global reduction in production to 2055, equivalent to a $2 billion dollar per year economic loss at the global scale (Jones and Thornton 2003).

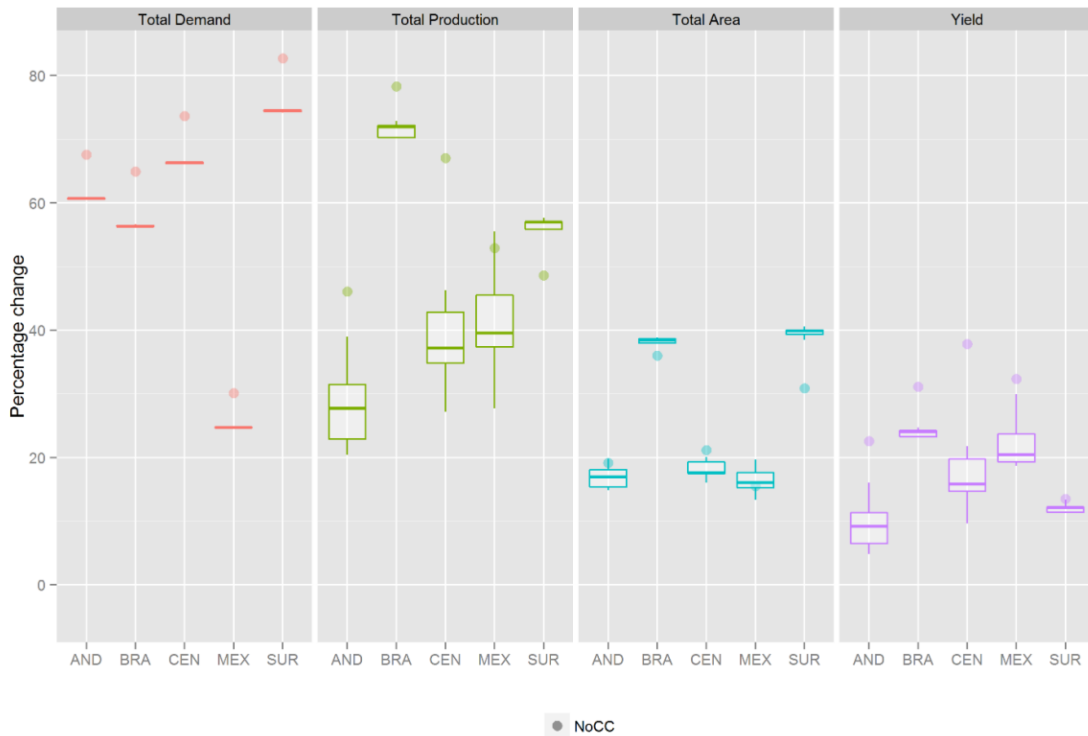


Figure 8: Percent change in key variables for climate change relative to the non CC scenario for maize.

The projected negative impact of climate change on maize yield it is reflected in a median decline in maize production in AND (-18 pp), CEN (-6 pp), BRA (-30 pp), MEX (-13 pp). These results are comparable with findings in a meta-analysis of observations drawn from over 1700 simulations (Challinor et al. 2014). Equally challenging, however, is that decreasing production may also accompanied by a 44% increase in global prices under climate change (Table 4). Though projected declines in maize demand differ among the sub-regions, in all cases, there are declines relative to the scenario without climate change.

Maize is an important commodity throughout Latin America and Caribbean and contributes to food security (Schmidt et al. 2012), both in terms of its role as a stable food commodity and as a feed grain. While four of five regions report median declines, the ability to trade internationally is affected by sub-regional total demand as well as by similar losses and gains in production elsewhere. Projected declines in both total demand and production thus lead to consistent increases in trade deficit net trade in the Andean countries, and Central America (Figure 9). However, uncertainty associated with modelling the impact of climate change on net trade it is illustrated clearly for BRA, MEX, and SUR to a lesser degree, where the range of simulated outcomes are comparatively broad. The model does indicate that, for AND and CEN regions, the trade deficit will worsen, again reflecting declines in total production principally as a function of declines in yield.

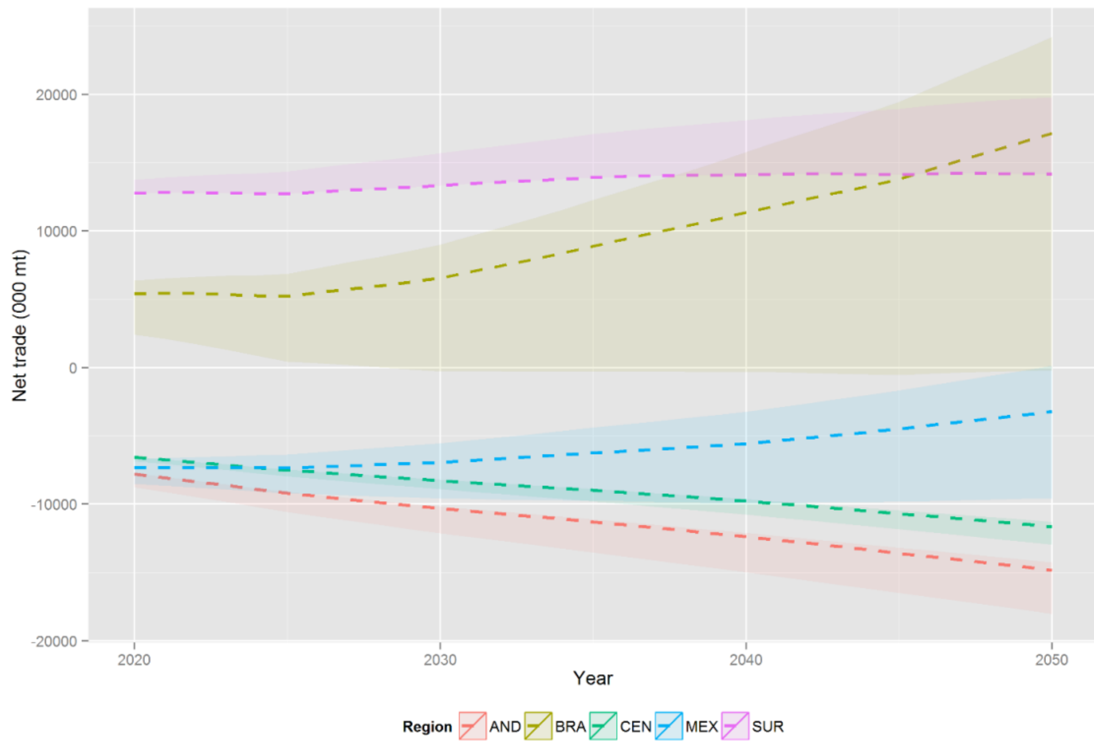


Figure 9: Tendencies for net trade of maize by climate model and region. The dotted line is change in trade without considering climate change.

The sub-regions that have the most potential to be adversely affected by climate change are CEN and AND. These areas will experience the most severe declines in maize yield under climate change and, given that a substantial number of small farmers in this region grow maize (Schmidt et al. 2012), climate change will likely add to existing pressures on the population.

3.2.3 Rice

As a crop heavily dependent on irrigation in most regions, rice is partially insulated from some of the effects of climate change. In LAC, irrigated rice comprises 59% of total rice production on approximately 37% of the total rice area (CGIAR 2016). Both the crop models and related IMPACT runs are configured to assume sufficient water availability for irrigated rice. As such, unless the temperature profiles exceed the threshold of those required for rice development, production of irrigated rice will not be as affected by lower than normal precipitation as would be other crops in this study. Though some commercial rice is grown in upland systems, the vast majority of rice in the region comes from irrigated systems.

Due to the abovementioned irrigation, rice is somewhat insulated from climate change in the model scenarios. IMPACT results indicate that climate change will be coincident with a net positive impact on rice production with BRA and SUR. In transitioning from no climate change scenarios with overall declines in rice production, BRA and SUR are estimated to see approximately 25 and 30 percentage point increases (respectively) in production (see Figure 10). These increases are most attributable to the combination of expected increases in yields as well as proportionally larger gains in the percentage points associated with area under cultivation. For AND, the climate change and no climate change scenarios are statistically similar and indicate declines in production of approximately 7.5 to 10%, most likely due to declines in demand and effectively no change in yields.

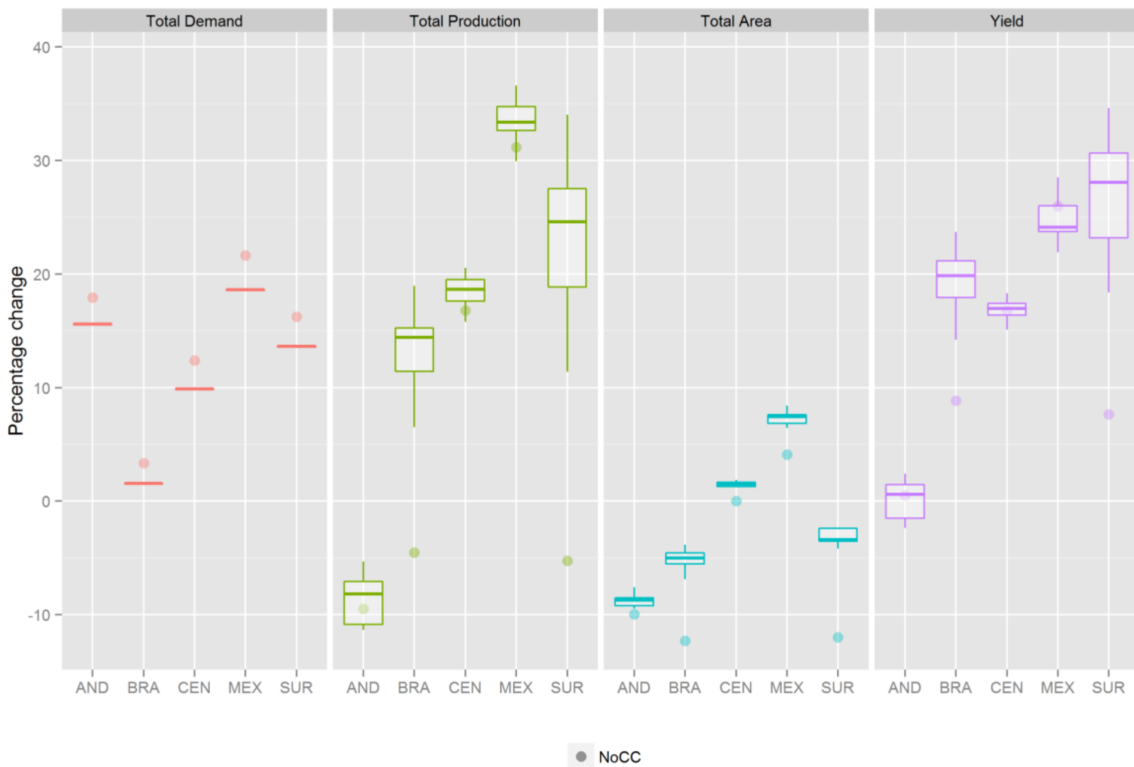


Figure 10: Percent change in key variables for climate change relative to the non CC scenario for rice.

Though rice has the potential to serve as an economic driver, there is substantial competition in the global market, especially from Asia which produces the vast majority of the global supply (Evenson and Gollin 2003). With climate change, the effects on potential for production of rice vary substantially across the LAC sub-regions and with the exception of AND, trend positively with climate change. The trade deficit is expected to increase in the AND sub-region both rapidly and consistently regardless of the climate model in question. In AND, climate change is thus magnifying the consequences of an already negative trend (see Figure 11). By 2050, trade deficit in AND has the potential to increase by approximately 270 percentage points.

In contrast to AND, though MEX has a greater decline in production, the effect on the trade deficit in MEX is small and in the opposite direction, with a decrease in the trade deficit of approximately 6 percentage points. This is likely a function of the smaller quantities of rice produced in MEX relative to AND. In SUR, though there is a trade surplus throughout the study period, the non-climate change scenario shows a modest yet sustained negative trend. The climate change scenarios serve to mitigate this trend initially, dampening the negative trend. Again, levels of net production are relatively low in SUR, but the minor warming that is predicted to occur in SUR (see (Gourdji et al. 2015) for details on the changes in temperature and precipitation) serves to positively affect trade. Like SUR, BRA shows increasing uncertainty over time with climate change. The results for CEN are generally as expected, with climate change serving to sustain an already substantial trade deficit.

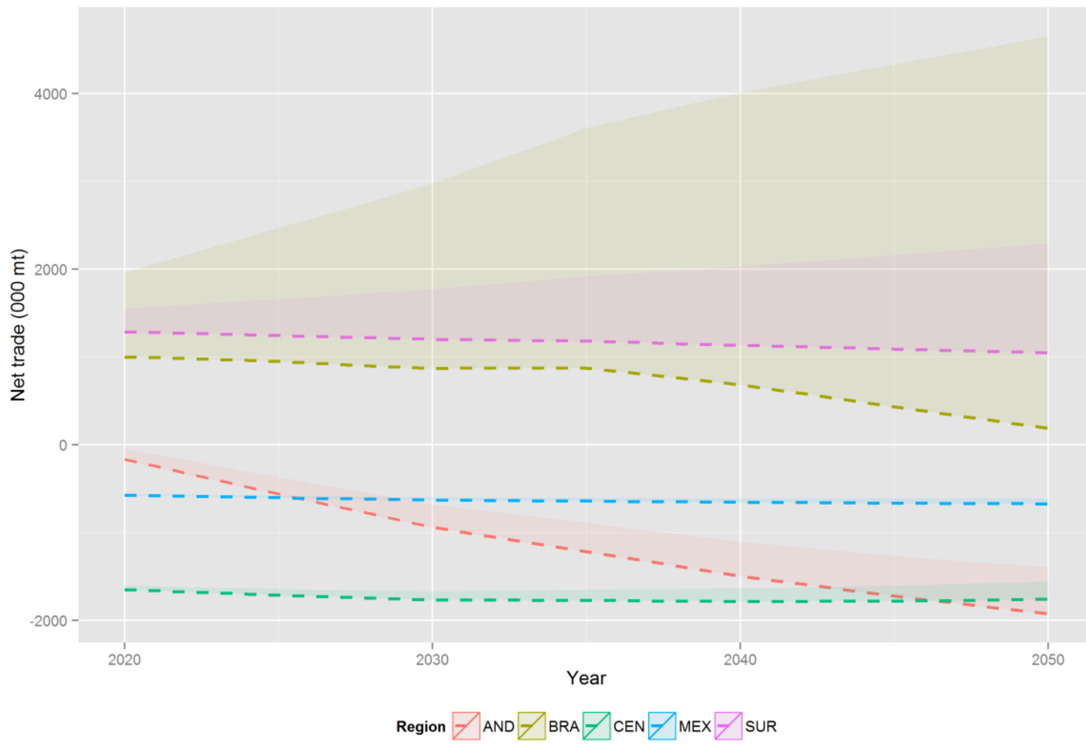


Figure 11: Tendencies for net trade of rice by climate model and region. The dotted line is change in trade without considering climate change.

A deeper examination of rice in LAC is useful as a basis for gaining insights into some of the broader implications of climate change, especially in the context of trade and where large portions of the population are reliant in imports of this key commodity (Trostle 2008). For example, in the Andean region, trade policies have resulted in a situation where profitability of rice is very unevenly distributed within the sub-region. The combination of high prices for inputs in Colombia coupled with a tight internal market and, additionally, policies generally favoring imports (Baffes and Gardner 2003), has contributed to the trade imbalances within the sub-region and likely to the overall trade deficit also found therein. This political economy could actually magnify potentially negative consequences of climate change.

Contrary to the popular view that trade liberalization could be the enemy of food security, some research has shown that liberalization of the rice sector in importing countries may alleviate poverty and improve food security, specifically by increasing supply and price stability (Gulati and Narayanan 2003). Whereas the IMPACT model generally assumes open trade, barriers to open trade such as disproportionally high prices for inputs and low levels of land availability as is the case in Colombia, or highly nationalized systems such as those in Venezuela are not directly modeled.

3.2.4 Soybean

Soy is a commodity crop that, while grown in LAC for human consumption, is principally traded as animal feed and, increasingly, for biofuels. As a flex crop (i.e., it is used for human consumption, animal feed and industrial uses), soybean production has been a key commodity driving land consolidation in many areas with LAC (Saturnino Jr. et al. 2012). Soy production is expected to increase substantially in the AND region according to the IMPACT model with all climate models showing an increase in production over the benchmark and a median change of over 20% over the non-climate change scenario. Likewise, BRA is expected slightly benefit from climate change with a median increase of 0.5% among the different climate models, though results are less definitely across the models (Figure 12). Declines in production are expected in both the SUR and CEN regions. For the southern cone, the rate of growth of soybean production shows a 1.9% median decline, while for CEN 4.3% reduction in production is anticipated.

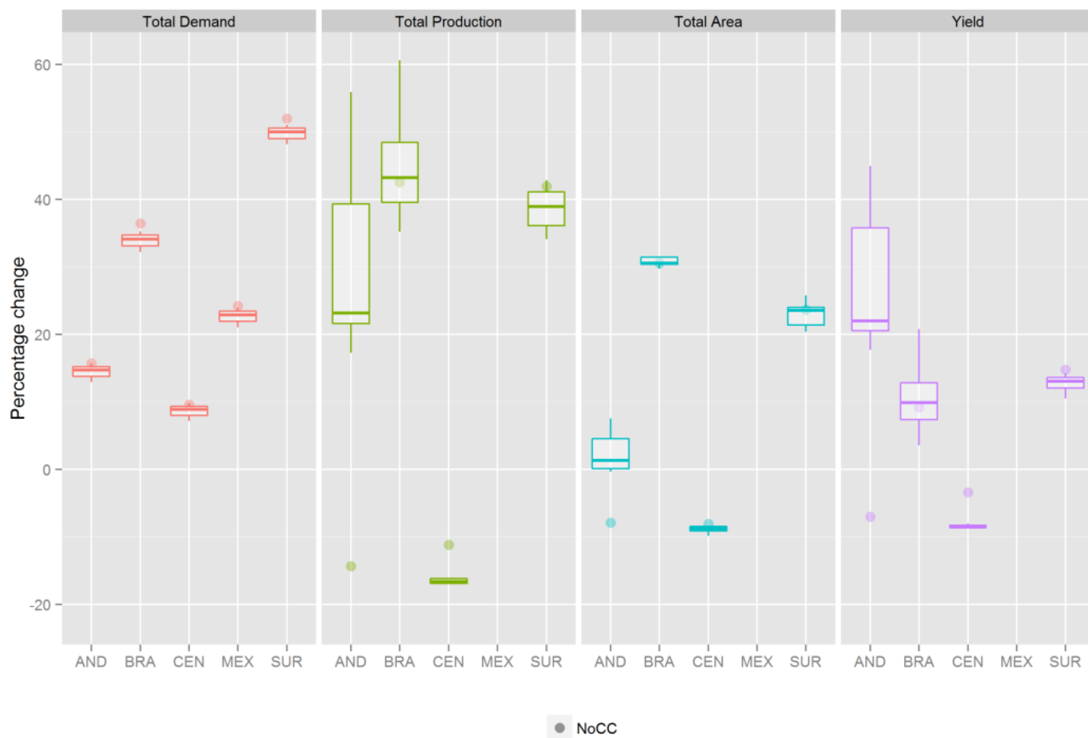


Figure 12: Percent change in key variables for climate change relative to the non CC scenario for soybean. Note: the IMPACT results do not include production for soybeans in MEX.

The international trade of soybean trends relatively consistently over time and as expected given the observed changes in production and climate model performance (Figure 13). Of note, however, is the proportionally large amount of soybean exiting BRA (approximately 2.5 to 3.0 times the next largest trade surplus in SUR). With such a large quantity being traded, the effect of climate shocks may be amplified in either a positive or negative direction for BRA and likely in the negative direction for SUR as the ranges of climate outcomes relative to the no-climate change scenarios illustrates (again, see Figure 13).

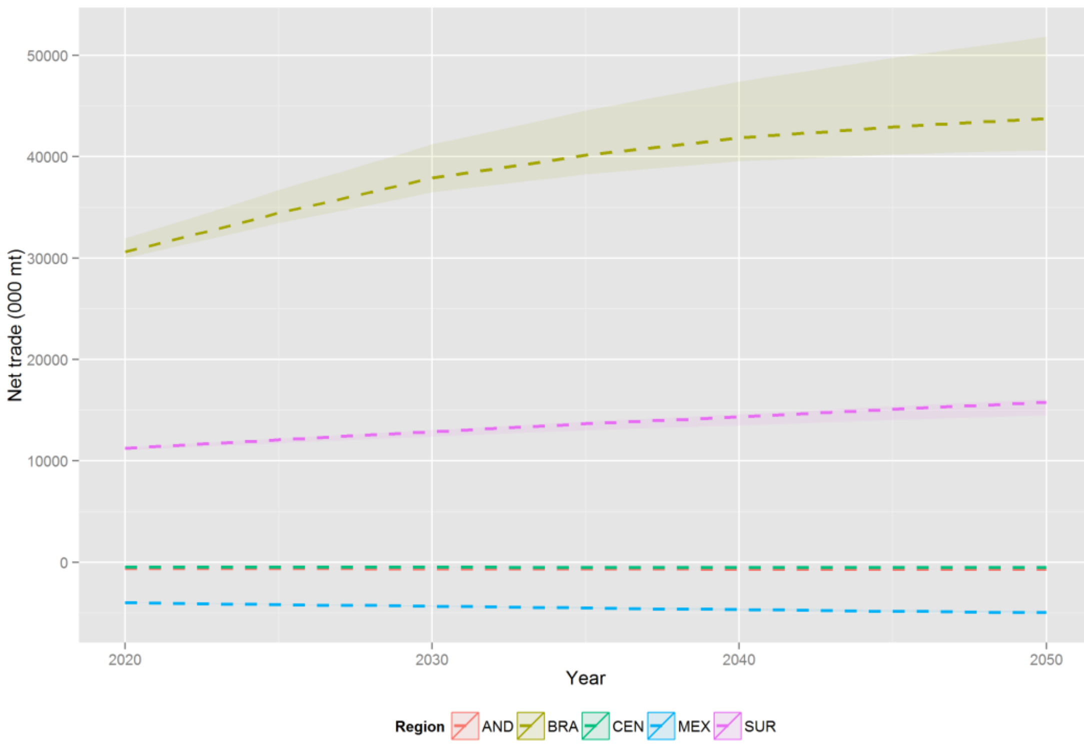


Figure 13: Tendencies for net trade of soybean by climate model and region.

As expected, without production of soybean, MEX has a substantial trade deficit and this deficit increases steadily over time due to proportional changes in sub-regional demand. The situation in AND and CEN is similar, however in both cases the trade deficit is nearly 10x smaller in each region and with net trade near zero. The more or less steady trends in the trade deficits in CEN, AND and MEX are a function or proportionally lower levels of production and lower exogenous shocks from climate-based yield models. Nevertheless, growth in soybean production is indicative of the increasing globalization of various economies within the LAC region (Grau and Aide 2008). Much of the soybean grown in LAC is exported to Europe and Asia (Dros 2004), suggesting both the possibility for increasing global integration associated with the positive trends in net trade of both SUR and BRA but also the need to recognize that changes in global prices will have the potential to have magnified effects within the region.

3.2.5 Wheat

Though wheat is grown throughout Latin America (FAO has no recorded wheat production in the Caribbean), it is one of the iconic and significant crops in the southern cone with more grown in SUR than CEN, MEX, and AND combined. BRA also has a high level of production as it dips into some of the more temperate areas in the southern portion of the continent. Wheat production is, however, universally negatively affected by climate change in LAC. Under climate change, declines in production are expected to range from approximately 5 to 25 percentage points relative to the non-climate change scenario (see Figure 14). These changes are driven by climate related reductions in yield as well as economically-based declines in area harvested in response to climate change. It is important to highlight the figures for MEX, wherein negative growth in production is anticipated in the study period worsening an already negative trend (Figure 14).

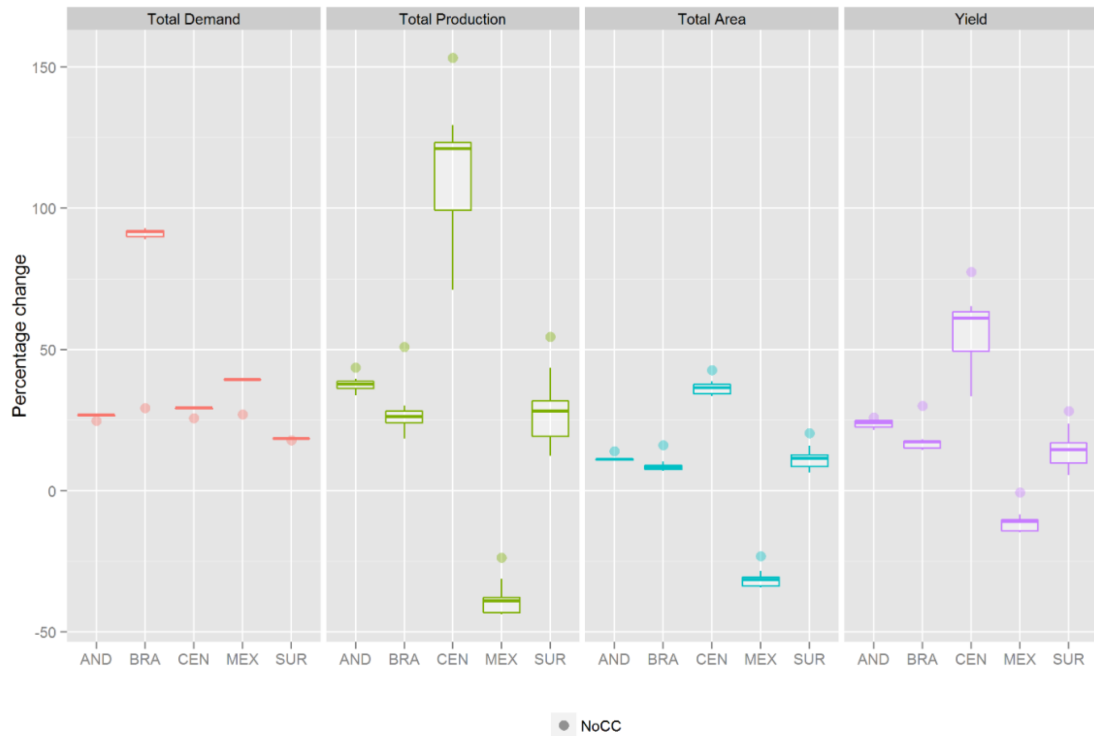


Figure 14: Percent change in key variables for climate change relative to the non CC scenario for wheat.

Increases in demand and relatively stable prices (referring back to Table 4) are driving increases in expected production of wheat even in the face of climate change. This is partly as a response to increasing use of the commodity in a biofuels context (Rosegrant, Zhu, et al. 2008). Nevertheless, the impacts of climate change are clear. Even in the best case scenario in SUR, each of the climate model scenarios reflects declines in production over the no-climate change scenario (Figure 14). The low existing levels of production are, in turn, driving the minimal amount of observed variation (see Figure 4).

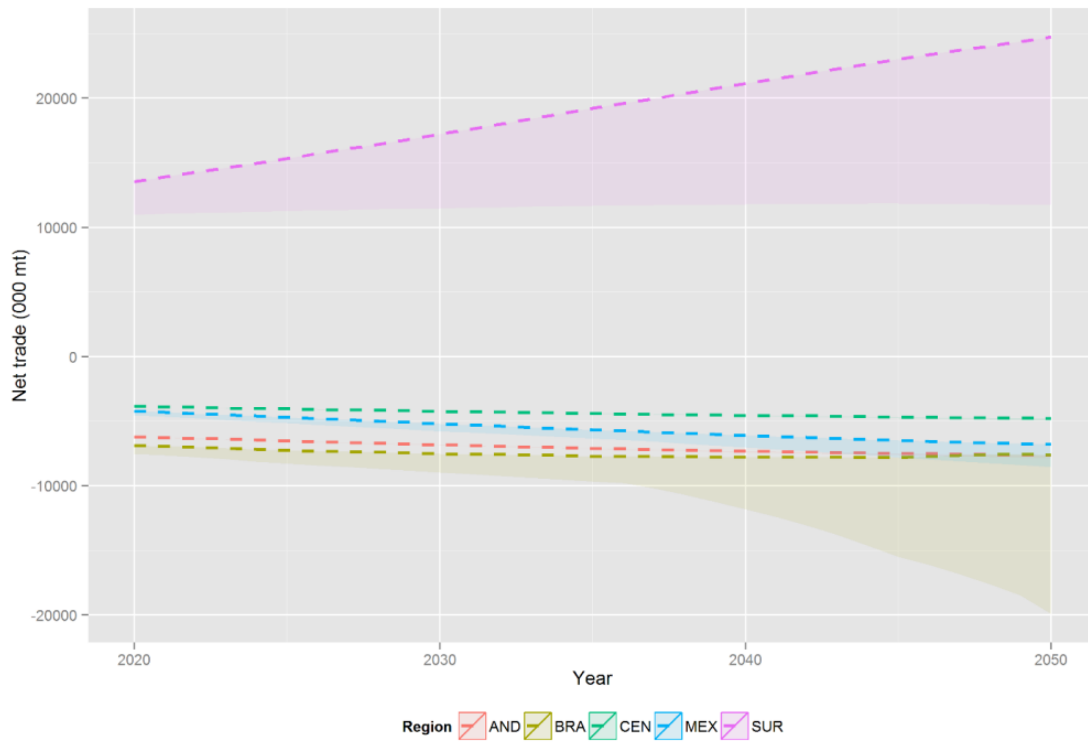


Figure 15: Tendencies for net trade of wheat by climate model and region.

In comparison to the other crops, changes in total demand for wheat are highly variable throughout the region. As with soy and maize, wheat is a flex crop with the potential to serve as a food crop for human consumption, an animal feed, or as feedstock for biofuels and other industrial uses (Borras et al. 2014). Demand in IMPACT reflects, "the sum of household food demand, agricultural intermediate demand (feed and processed goods), and intermediate demand from other sectors (that is, for biofuels and industrial uses)," (Robinson et al. 2015). The International Center for Improvement of Maize and Wheat estimates that in 2020, approximately 60% of wheat utilization in LAC will be for feed (*Global Trends Influencing CIMMYT's Future* 2003). The observed growth in demand for wheat as well as other commodities dependent on wheat (e.g., animal protein), thus has the potential to substantially pressure the trade deficit of these two regions, especially in MEX where substantial declines in production are expected, and BRA, where relative reduction in production due to climate change occurs in the midst of high increases in demand.

3.2.6 Summary of crop-related response to climate change

The previous sections illustrate that the role of each of the five study crops in LAC is regionally dependent. Three of the five crops are "flex crops" and thus have demand profiles based on human, animal and industrial demand. Depending on the crop, the sensitives of the crop to current and future climate conditions and the specific sub-region in which the different crops dominate, changes in production may vary quite substantially depending on the climate model. The sub-regional differences illustrated how local response to climate could cause both crop production and corresponding trends in net trade to vary differentially across the region as a whole (see Table 6).

Table 6: Consolidated results by crop and region.

Crop	Economic Transition
Dry bean	Key food crop supporting increased food security. Stable demand. Climate change related declines in production with the exception of SUR. High potential for trade surplus in BRA and SUR. Indefinite in AND and CEN. Shift toward increasing trade deficit in MEX.
Maize	Flex crop with complex demand profile. Downward pressure in demand associated with climate change scenarios. Potential for trade surplus in BRA and SUR. Substantial trade deficit in AND and CEN. Long term potential for reduction of trade deficit in MEX.
Rice	Key food crop supporting increased food security. Downward pressure in demand associated with climate change. Decreasing trade in AND. Increasing uncertainty in trade for BRA and SUR.
Soybean	Flex crop with complex demand profile. Modest downward pressure in demand associated with climate change. Increasing potential trade in SUR and BRA, with relatively stable trends in trade through the remainder of the sub-regions.
Wheat	Flex crop with complex demand profile. Increased in demand under climate change. Declines in net trade in AND, BRA, MEX and CEN. Increases in trade in SUR, but with gains potentially offset by climate change.

Finally, though trends for regional trade are crop and sub-region specific, the systematic adjustments (i.e., the shifts in rates of change as a function of the exogenously determined intrinsic productivity rate or IPR) affected each climate change scenario in a similar manner. Though the observed trends in international trade are ultimately a function of the effects of both the exogenous and endogenous variables, including the different factors affecting demand composition, changes in factors such as the IPRs typically serve to deflect existing trends rather than fundamentally change their direction. This finding supports the conclusion that it would take massive economic shifts in both the domestic and international markets in order to reverse an established trend. In the cases where structural changes do change the sign in the trend, the changes unfold over many years in the model results.

Regional variation and long timeframes to realize change in agriculture systems underscore the need for decisive actions with regional specificity. Agriculture both serves as an important source of employment for the poorest populations and serves as an important source of income and food security for the rural poor and context-specific adaptation strategies are critical (Fischer et al. 2005). In terms of food security, crops serve multiple economic roles. Crops are traded domestically and represent an internal resource for both kilocalories and income. Likewise, when surpluses are available, the regional global markets can be used to facilitate integration, generate further income, potentially improving access to food. Given the key role of dry beans, maize, rice, soybeans and wheat both as staple crops as well as income generators, the next section reviews how the changes in production relative to climate change have the potential to affect food security.

3.3 Contextualizing changes in food security

From an ex-ante perspective, understanding the effects of climate change on food security requires understanding the difference in change in food security under climate change versus the status quo. As highlighted in Schmidhuber and Tubiello (2007), one implicit hypothesis is that economic development will have a positive effect on food security of the population. Thus, in an ex-ante context, the question that must be asked is whether or not the positive effect of economic development on food security has the potential to be diminished or amplified by climate change. Put another way, will areas in LAC maintain either an adequate self-supply of food, or otherwise generate levels of economic activity sufficient to efficiently engage the global market as net importers (Sakschewski et al. 2014)?

Food security in food systems is driven by a complex mix of aspects ranging from kilocalorie availability to distributional equity, to adequate surpluses supporting trade. As with the crops detailed in the previous section, food security is regionally and context dependent. For this reason direct measures of food security are somewhat elusive, and understanding from a macroeconomic perspective offers, at best, an indication of necessary but not sufficient conditions for food security at the household level (Webb et al. 2006).

In the IMPACT model, indicators of food security are calculated at the national level. As detailed in Table 3, the principle indicators regarding food security include an estimate of the number of malnourished children based on an adaptation of a model developed by Smith and Haddad (2000), and estimates for the share of the population at risk of hunger, based on work of Fischer et al. (2005). In general terms, the increases in the prices as observed in Table 4, coupled with the trade deficits observed in many of the crop by sub-region analyses, hint at the possibility for increased exposure to food insecurity and are similar to findings highlighted by Fisher et al. (2005) and Rosegrant et al. (2014). For example, with global prices for dry beans, maize and rice facing potential increases of 50% or more under climate change than would be expected given current conditions, there is high potential for additional pressure on those households with already high expenditures on food (Hertel, Burke, and Lobell 2010). Simultaneously, from a regional perspective, the Andean region and Central America and the Caribbean are all operating under trade deficits with respect to these critical staple and economic commodities.

How can we understand the potential consequences of these complex dynamics? As mentioned in the introduction, food security can be better understood through indicators in the four dimensions of availability, stability, access, and utilization (Schmidhuber and Tubiello 2007). The IMPACT model allows inference about these factors and, specifically, whether or not climate shocks appear to be diminishing gains associated with development outcomes. Beginning with an overview of how climate change appears to affect food availability generally, as well changes in the number of people at risk, the analysis then proceeds to an examination of the relationships between food security and the variables linked to changes in food security measures. Based on these relationships, the comparative changes, with and without climate change, in people at risk of food insecurity are analyzed by sub-region.

Given the importance of caloric self-supply, especially is developing regions (Sakschewski, von Bloh, Huber, Müller, & Bondeau, 2014), understanding sub-regional food availability is an important first step. If food supplies are inadequate to meet the food demanded by the population, the population may be at risk of food insecurity. Figure 16 illustrates relative food availability through the ratio of food supply to food demand in each of the study sub-regions without considering food supply coming from international trade. For example, a ratio of 1.5 indicates that a sub-region produces 1.5 tons of food for every ton of food needed, assuming no additional supply via trade. Thus, ratios greater than 1.0 are indicative of the potential for food sovereignty (Altieri, Funes-Monzote, and Petersen 2011), and ratios of less than 1.0 indicate greater dependence on imports and potentially lower resilience to future food crises (Rosset 2008). Whereas SUR has a surplus that has the potential to bolster food security, the rest of the regions are near and below parity over the course of the model run. The relatively strong growth in production in SUR (see Table 6 for a regional perspective) coupled with proportionally lower increases in demand lead to food surpluses and potential for greater food security, especially in comparison to the less wealthy AND, CEN and MEX regions.

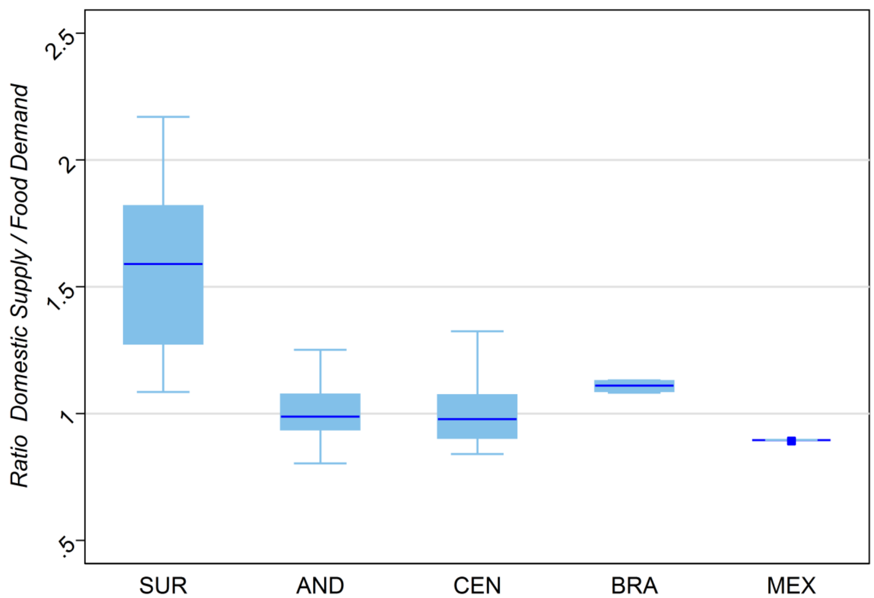


Figure 16: Relative food availability in 2050.

Based on the above, it is clear that IMPACT model results suggest that the negative consequences of climate change on food security are unequally distributed throughout LAC. Equally important, however, is that the variables driving exposure to food insecurity differ from region to region and country to country. The geographical distribution of number of individuals exposed to hunger under the climate change serves to illustrate this phenomenon (Figure 17). Figure 17 illustrates that both the absolute and relative effects of climate change on food security are geographically varied. For example, while Honduras is estimated to have a larger share of its population exposed to risk of hunger, the proportional impact of climate change has the potential to be more substantial in the Dominican

Republic.

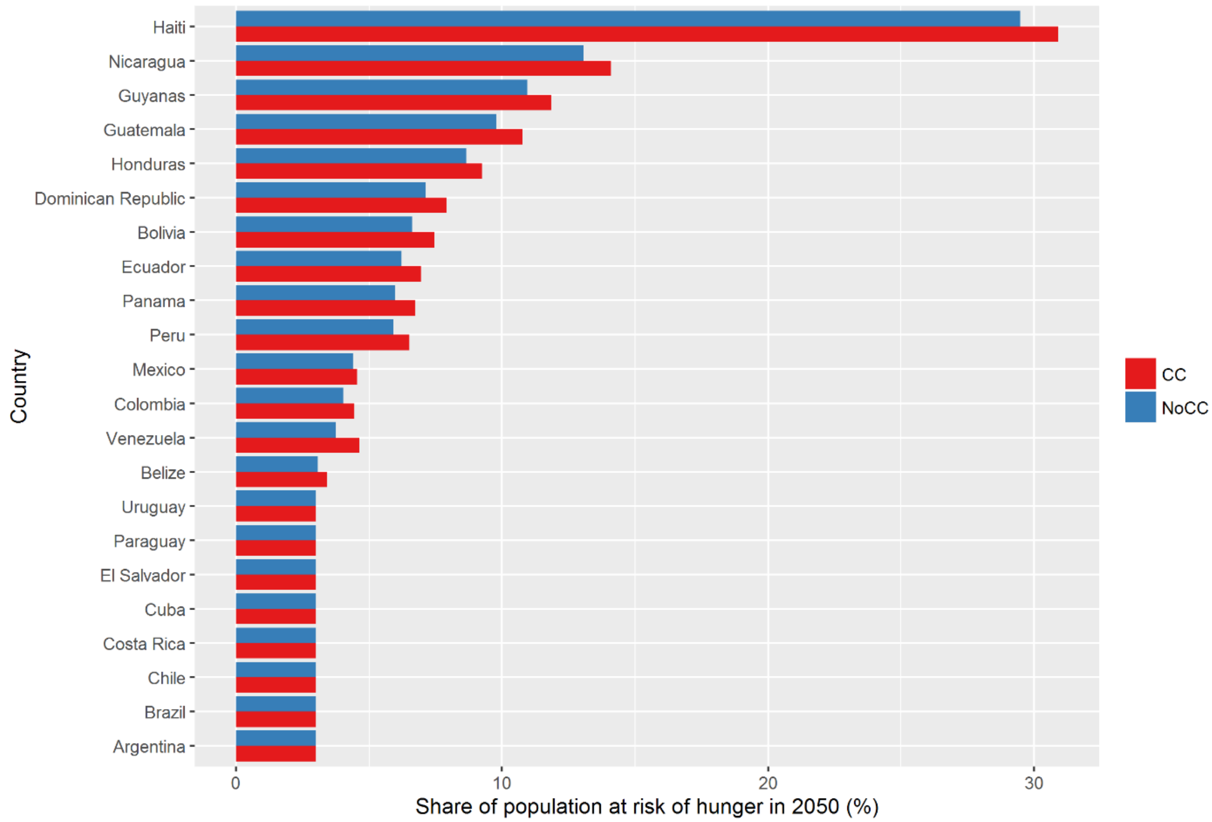


Figure 17: Relative change in risk of exposure to hunger attributable to climate change.

As with actual economies in LAC, food security in the modeled economy in IMPACT is associated with a number of drivers. In the IMPACT model, changes in food security are linked to changes in a number of variables including food availability, total expenditure on food, GDP per capita, import dependence, projected changes in malnourished children and, share of people at risk of hunger. In order to parse the interrelationship between these variables and food security, correlations between typical economic indicators and food security offer insight regarding how climate change will differentially affect the different dimensions of food security.

Under conditions of climate change, increases in the availability of food, whether driven by increases domestic production or imports, have a significant impact on food security. As would be expected, results indicate that increases in the changes of both food availability and per capita calories are correlated with improvement in food security indicators (Table 7). Likewise, as expected, the results indicate that increases in GDP per capita are associated with increases in purchasing power, thus supporting improved access to food. By extension, declines in GDP growth relative to population growth, or declines in GDP as a function of negative impacts associated with yield shocks will tend to reduce the progress that could be achieved in the region to improve food security in the absence of climate change.

Table 7: Correlation between food security indicators under conditions of climate change.

	Per Capita Income	Expenditure	Per capita calories available	Share at Risk of Hunger	Malnourished Children	Food Availability
Per Capita Income						
Expenditure	0.53***					
Per capita calories available	0.71****	0.56***				
Share at Risk of Hunger	-0.37*	-0.47**	-0.55***			
Malnourished Children	-0.29	0.06	-0.05	0.23		
Food Availability	0.56***	0.55***	0.89****	-0.52**	-0.15	
Import Dependence	0.16	0.1	0.16	0.1	0	0.13

Significance of Correlation: **** p<0.1%; *** p<1%;** p<5%; * 10%

Perhaps less expected is that, at the LAC regional level, import dependence it is not highly correlated with any of the food security indicators. Other studies have illustrated that import dependence may contribute to increases in food availability, thus improving food security (Food and Agriculture Organization 2015). Even so, the results suggest that food security can be improved by promoting policies that aim to increase food accessibility and availability. Research and development in agricultural technology and improved food systems will have the potential to close yield gaps and increase food availability, (Rosegrant et al. 2014), while policy or economic growth resulting in improved GDP will tend to increase accessibility (Godfray et al. 2010).

Finally, an important consideration is the relative efficiency by which changes in food availability translate to improvements in the number of people at risk of hunger. As Figure 18 illustrates, on average, the combined trajectories indicate that the share of people at risk to hunger begins to decline in response to food availability. However, as the curve in the average trend illustrates, it takes proportionally greater food availability to achieve smaller improvements over time. For LAC, Figure 18 illustrates that countries in LAC, in comparison to the rest of the world, reach some of the lowest levels of exposure to hunger with proportional lower food availability than many other countries.

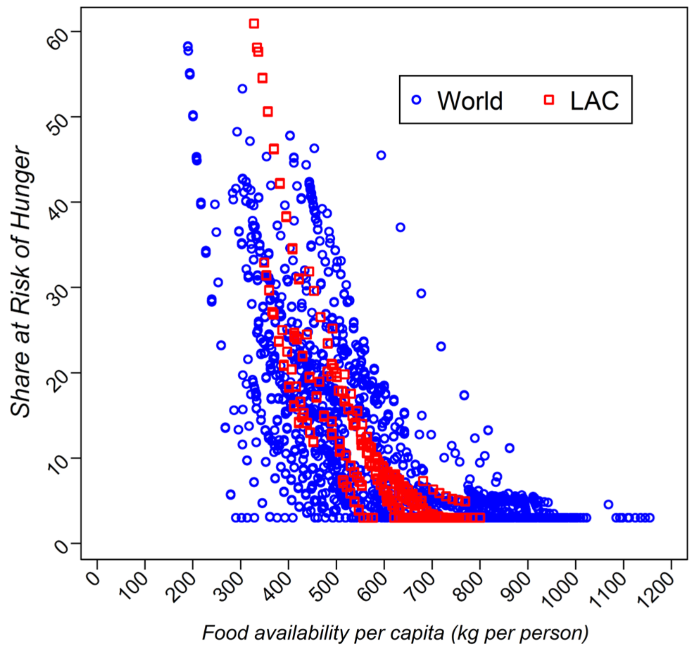


Figure 18: Comparison of LAC vs. World in reducing exposure to hunger, 2020 - 2050. Note that 5% is the floor of the values due to model limitations.

Though it is clear that, by 2050, there are several countries in LAC with populations that will be substantially exposed to risk of hunger, Figure 18 offers some positive perspective. In that LAC countries achieve lower percentages of share at risk to hunger with lower food availability, suggestions a certain conversion efficiency that many other countries do not have. This efficiency has the potential to build on more general improvements in resource use (Parry and Hawkesford 2010), and is an area that should be examined in future policy contexts.

3.4 Summary of analysis

Many different aspects related to crop production, economic activity and food security in LAC will be affected by climate change according the IMPACT model (Rosegrant et al. 2014). The economic impact associated with the five study crops is principally through declines in production that result from lower yields and reductions in area harvested. The lower yields are driven by poorer performance of the crops given climate conditions, and changes in area harvested are in response to both endogenous and exogenous components of the model. It should be reiterated that this analysis does not explicitly consider specific adaptation measures such as new crop technology, improved agro-climatic forecasts, or other short-term adaptation with the potential for improving marginal returns. Given the scale of the climate effects and the lack of short-term adaptation in the model, declines in production will generally result in increased prices as demand exceeds supply. This, in turn, exacerbates the challenges for the poorest consumers for whom food comprises a largest portion of their household expenses.

When evaluating the overall results of the crop by sub-region analyses (see Section 3.2.6) alongside the results of the food security analysis, it is clear that the Andean sub-region, the Mexico sub-region, and Central America and the Caribbean sub-region would face substantial difficulties in the modeled scenarios. The Brazil region is, in some sense, sheltered from some of the economic impacts of climate change due to its economies of scale associated with maize and other IMPACT commodities. Even in the face of climate change, BRA is expected to grow its trade surplus in maize, rice, and soy. In many regards the southern cone is similarly sheltered from the most adverse impacts of climate change due to increasing suitably for crops that will encounter difficulties elsewhere in the region, through surpluses in dry bean, maize and rice. Both BRA and SUR have positive food supply to demand ratios and thus the populations are less likely to face food insecurity if access can be maintained through appropriate pricing and support mechanisms related to both the domestic and international markets (Hertel and Keeney 2006).

Given the expected increases in both producer and consumer prices, LAC may face further obstacles in the global marketplace if its relative costs of production exceed those of other regions. The results within LAC are highly heterogeneous, however, with regions and countries facing different issues with the different crops. Policy to improve competitiveness of LAC producers will not only help to reduce prices of regionally produced commodities, but will also help these commodities in the global marketplace. If accompanied by policies designed to improve the agriculture system itself (e.g., through closing yield gaps), there is increased potential for a more stable and integrated role for agriculture in the economic development process (Barbier 2004).

Though relative food availability is suboptimal in AND, CEN and MEX, all countries in the region exceed the minimal WFP food basket requirement of 2100 dietary calories per day (Figure 19). Though Figure 19 indicates that, on average, the net food produced across all commodities in IMPACT, including the five specifically modeled in this study generally exceeds the minimum caloric requirement of the WFP, this does not take into account climate variability and that countries with marginal surpluses in dietary calories may be more subject to the negative consequences associated with this variability. Likewise, some countries saw relatively little growth in dietary calorie availability during the study period. The overall context must be considered and in cases where declines in production are coupled with trade deficits, population increases, and increasing exposure to hunger, a weakening economic situation will slowly, but surely, diminish the ability of the region and its countries to respond to the impacts of climate change.

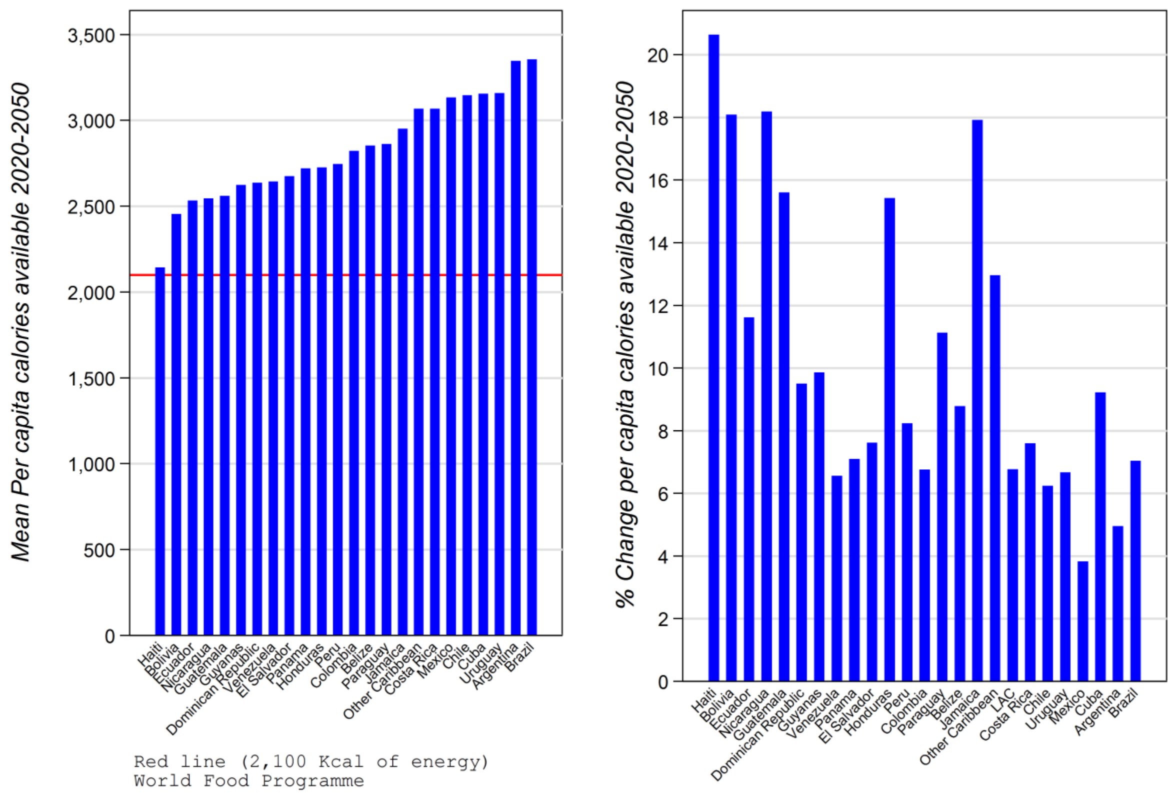


Figure 19: Mean food availability in kg/person/year and percent change in the same time period.

Importantly, as with any model, the results from IMPACT are a function of the inputs, and the uncertainty from the input data is propagated through to the economic analysis. In spite of the uncertainty associated with introducing the climate shocks into the model, in many cases the trends are relatively consistent. Universally, however, when other exogenous shocks are introduced (e.g., changes in the intrinsic productivity rates), these are clearly reflected in the model results. Again, this underscores that policy that has the potential to influence the production of the different crops (e.g., consumer and producer support, investment in research and development, etc.) has the potential to be effective across a broad range of climate scenarios.

4 Implications and conclusions

The impacts of climate change in Latin America and the Caribbean, as measured through the economic impacts of crop yield shocks on the economies of the region, are highly heterogeneous by both region and the crops in question. Though this analysis is based on a reasonably conservative set of scenarios and underlying assumptions (SSP2 and RCP4.5), the results from the IMPACT model indicate that every region will see negative trends in production for one or more of the five modeled crops. The magnitude of the changes varies substantially across sub-regions and crops, but no region is completely free of climate-related declines in production.

It is critical to note that one of the key factors driving production over time is the aforementioned "exogenous" intrinsic productivity growth rate or IPR. IPRs are defined at the food production unit level within each country and represent how external factors such as technology improvement (or lack thereof) may positively or negatively affect growth in production over time. The IPRs thus serve as potential entry point into the policy domain and represent an opportunity to think about how policy that would affect IPRs in certain sub-regions will play out economically and in relation to food security over the long-term. This analysis does not directly address adaptation to climate change but IPRs (and improvements therein) are one mechanism that has the potential to help countries respond in the most appropriate and efficient manner given their agro-environmental context.

One critical element missing from this analysis is any consideration related to severe and short-term impacts related to climate variability. The IMPACT model is a global scale model with yield shocks derived based on differences in long-term trends. Given the resolution of the model, extreme events are therefore out of scope. Nevertheless, the importance of extreme events and, likewise, the importance of including these phenomena in climate models have been long recognized (Katz and Brown 1992). Concern regarding the effects of extreme events on food production is also well established (Rosenzweig et al. 2001). Though the effects of extreme events tend to be sub-regional or at the local level, the economic and food security impact of an extreme event in a critical part of the growing season or in a key production area could ripple through the region. For this reason, policy that serves to bolster regional agricultural resilience will serve to buffer the region from extreme climatic events.

Finally, it is important to restate that the economic impact of climate change to agriculture in Latin America and the Caribbean is linked to impacts of climate change elsewhere around the globe. Prices for traded commodities (both in IMPACT and in the actual global marketplace) are driven both by prices for inputs (including labor and other capital) as well as more global supply and demand interactions. Policy designed to increase the resilience of agriculture in Latin America and the Caribbean should thus consider the effects of climate change elsewhere in the world. If, for example, a LAC-produced commodity cannot be competitively sold on the global market due to differences in regional vs. global producer and consumer prices, then investments to improve that commodity should be carefully reviewed and considered.

Latin America and the Caribbean is a complex mix of economies at different levels of development and with different exposure to climate change. As agricultural policy moves forward, it should take into account that different crops and related commodities will be more or less viable and more or less subject to climate change impacts as well as impacts in prices of inputs and other factors affecting costs of production and, ultimately, trade balance. This report serves as a starting point for understanding these interactions and highlights potential opportunities and potential risks throughout the region.

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6 Appendices

Three appendices are provided to support the material presented in the report. We include an appendix highlighting a brief study on the effects of aggregation in the data generation process. Second, we present a brief description of the tables and geospatial information provided in association with this study. Finally, we present a series of tables of key indicators for each region over the period modeled in.

6.1 Appendix 1 – Analysis of Aggregation of Crop Model Results

The crop model results in this study were generated using a distributed crop model approach wherein crop yields were estimated using DSSAT for each pixel (0.5° spatial resolution) in the study area. In order to understand if climate change may have a statistically significant effect on crop yields, we study the differences between crops yields between the baseline in each of the 9 future scenarios (GCMs) by crop and system (irrigated and rainfed). Differences are examined in yield characteristics at the both the individual pixel and aggregated Food Production Unit (FPU) levels. As with the previous climate change study (Gourdji et al. 2015), results of this study indicate the potential for climate change shocks to affect crop yields at the pixel level. The results indicate that at the FPU level, however, there is some potential for the introduction of a composition effect. This appendix presents a brief analysis and discusses the issue.

Using the Wilcoxon rank sum test (R Core Team 2014), pixel values were evaluated between the baseline and future periods. At a pixel level, the median yields in the baseline period are statistically significantly different than the projected median yields in the future period. In other words climate change may have an impact, positive or negative, on yields for each of the analyzed crops. These statistically significant differences were observed in both irrigated (Table 8-A1) and rainfed systems (Table 9-A1).

Table 8-A1: Irrigated system P-values for the Wilcoxon rank sum test of the baseline vs. future yields at the pixel level.

	Rice	Maize	Soybean	Bean	Wheat
bcc_csm1_1	0.00	0.00	0.01	0.00	0.00
bnu_esm	0.00	0.00	0.00	0.00	0.00
cccma_canesm2	0.00	0.00	0.00	0.00	0.00
gfld_esm2g	0.00	0.00	0.00	0.00	0.00
inm_cm4	0.00	0.00	0.14	0.00	0.00
ipsl_cm5a_lr	0.00	0.00	0.00	0.00	0.00
miroc_miroc5	0.00	0.00	0.00	0.00	0.00
mpi_esm_mr	0.00	0.00	0.00	0.00	0.00
ncc_noresm1_m	0.00	0.00	0.00	0.00	0.00

Source: Authors' calculation.

Table 9-A1: Rainfed system P-values for the Wilcoxon rank sum test of the baseline vs. future yields at the pixel level.

	Bean	Maize	Rice	Soybean	Wheat
bcc_csm1_1	0.00	0.00	0.00	0.54	0.00
bnu_esm	0.00	0.00	0.00	0.00	0.00
cccma_canesm2	0.00	0.00	0.00	0.00	0.00
gfld_esm2g	0.00	0.00	0.00	0.00	0.00
inm_cm4	0.00	0.00	0.00	0.07	0.00
ipsl_cm5a_lr	0.00	0.00	0.00	0.00	0.00
miroc_miroc5	0.00	0.00	0.00	0.00	0.00
mpi_esm_mr	0.00	0.00	0.00	0.00	0.00
ncc_noresm1_m	0.00	0.00	0.00	0.00	0.00

Source: Authors' calculation.

As each of the preceding tables illustrates, there is very high concordance across crops, system type, and climate models with respect to the significance of each test. In nearly all cases, there is very strong support (low P-values) for the conclusion that the values from each of the two time periods are drawn from different distributions. This observation, in turn, supports the conclusion that climate changes impacts are observable across the two time periods.

An examination of baseline versus future period at the FPU level yields a somewhat different picture. In approximately one third of the crop/climate model combinations, there are no statistically significant differences between the baseline and future period. For the irrigated (Table 10-A1) and rainfed systems (Table 11-A1), the aggregated results for both rice and soybean are not clearly differentiable between the baseline and future periods.

Table 10-A1: Irrigated system P-values for the Wilcoxon rank sum test of the baseline vs. future yields at the FPU level.

	Bean	Maize	Rice	Soybean	Wheat
bcc_csm1_1	0.00	0.00	0.62	0.20	0.00
bnu_esm	0.03	0.00	0.95	0.07	0.00
cccma_canesm2	0.02	0.00	0.54	0.15	0.00
gfld_esm2g	0.01	0.00	0.35	0.29	0.00
inm_cm4	0.00	0.00	0.69	0.78	0.00
ipsl_cm5a_lr	0.00	0.00	0.55	0.01	0.00
miroc_miroc5	0.00	0.00	0.12	0.46	0.00
mpi_esm_mr	0.01	0.00	0.89	0.02	0.00
ncc_noresm1_m	0.00	0.00	0.36	0.78	0.00

Source: Authors' calculation.

Table 11-A1: Rainfed system P-values for the Wilcoxon rank sum test of the baseline vs. future yields at the FPU level.

	Bean	Maize	Rice	Soybean	Wheat
bcc_csm1_1	0.02	0.00	0.64	0.32	0.00
bnu_esm	0.00	0.00	0.56	0.86	0.00
cccma_canesm2	0.00	0.00	0.71	0.32	0.00
gfld_esm2g	0.00	0.00	0.16	0.00	0.00
inm_cm4	0.00	0.00	0.48	0.41	0.00
ipsl_cm5a_lr	0.00	0.00	0.39	0.00	0.00
miroc_miroc5	0.00	0.00	0.66	0.07	0.00
mpi_esm_mr	0.00	0.00	0.73	0.10	0.00
ncc_noresm1_m	0.00	0.00	0.59	0.39	0.00

Source: Authors' calculation.

Though some of the climate models show distinctions in the distributions associated with the baseline and future periods for soybean in both irrigated and rainfed systems, none of the of the models offer clear differentiation between baseline and future periods for rice. The inconsistency of the pixel and FPU level results indicates that, especially for rice and soy, there are some pixels with yield increases in the future period and others with yield decreases. Whereas for the pixel-level results, the differences (independent of direction) are captured by the rank sum test, for the aggregate results, the increases and decreases within the FPU effectively offset one another.

While the aggregation effect will mask changes at the pixel level, the estimates of net changes in yield generated at the FPU level are still suitable for the economic analysis. Simply put, estimates of the economic impact of climate change on rice and soy will consider that there will be both positive and negative impacts within the same FPUs. In contrast, for the other crops, the changes within any FPU are more consistent and trend either positively or negatively depending on the crop.

6.2 Appendix 2 – Summary of Available Datasets

Multiple datasets were generated in the course of the economic analysis. The values in these datasets were connected to their respective map locations using the Food Production Unit (FPU) names as the basis for joining the tabular and map data. All of these data are made available in both tabular and map form at the data portal developed for this effort. The data portal can be accessed at:

http://arcg.is/21tTP5J

The following table summarizes the delivered datasets, including a brief description of the dataset itself, included fields, and other notes related to the use of the data.

Table 12-A2: Explanation of data.

File Name	Brief Description	Fields	Comments
Climate Change effect on yields (CCDelta) - FPU	Climate change shock on yield growth.	CROP – crop type TREAT – system type bcc_csm1_1 - GCM bnu_esm - GCM cccma_cane - GCM gfld_esm2g - GCM inm_cm4 - GCM ipsl_cm5a_ - GCM miroc_miro - GCM mpi_esm_mr - GCM ncc_noresm - GCM FPU – Food production unit	Each row in this table contains the climate shock values for each GCM for one FPU, one crop, and one system type (irrigated or rainfed). The values in this table are provided for reference only. The entries for each crop, system type, and climate model are calculated using the procedure described in Section 2.3.
Food security - Countries	Food security variables by country.	GCM – climate model IMPACT_Var – food sec. var. Year_2005 - 5 year increments to - Year_2050 COUNTRY - country flag	Each row in this table provides one of three key food security variables (malnourished children, population at risk for hunger, share at risk for hunger), the corresponding climate model from which the estimate was derived, values for each 5 years of the modeled future period, and the country.
Food security - Region	Food security variables aggregated to the whole LAC region.	See Above REGION – LAC aggregate flag	See Above.
Prices –	Estimated	CROP – crop type	Each row contains one of the

Region	producer, consumer and world prices.	GCM – climate model IMPACT_VAR – price vars. YEAR_2005 - 1 year increments to - YEAR_2050 REGION – LAC aggregate flag	three price variables (producer, consumer, or world prices), the crop and climate model for which the price was calculated, and the corresponding price values in $US (2005) per metric ton. Prices are presented in one year increments from 2005 to 2050. It should be noted that prices are modeled for purposes of equilibrating the model and should NOT be taken as representative of actual prices.
Production and demand – Subregion	Estimated production and demand of each crop by sub-region.	CROP – crop type GCM – climate model IMPACT_VAR – price vars. Year_2020 - 1 year increments to - Year_2044 tc_2020_20 REGION – sub-region aggregate flag	Each row contains one of the five key variables (net trade, total area, total demand, total production and weighted yield), the crop and climate model for which the variable was calculated, and the correspond sub-region for which the data were aggregated. Note that the units for the values in in the IMPACT_VAR column will vary as a function of the variable (metric tons or area in hectares).

On the interactive website each of the above tables can be queried using the map interface. It should be noted that any analysis of the presented data should account for the variation associated with the multiple climate models and the variation associated therewith.

6.3 Appendix 3 – Summary key variables by sub-region

In order to provide an "at a glance" reference of key economic and food security indicators at the sub-regional scale, the data for the future period are extracted and consolidated from the IMPACT results.

Table 13-A3: Key climate change variables by sub-region.

Sub-region	Year	Estimated Population (millions)	Average per capita calories available (KCal per person per day)	Food availability per capita (Kg per person)	Share of population at risk of hunger (%)	Export Share of Production (%)	Net Trade (000 mt)	Import Share of Demand (%)
AND	2020	144.6	2513.0	528.4	14.0	4.4	-1221.3	17.1
	2025	151.6	2555.0	541.0	12.4	4.8	-1065.1	17.2
	2030	157.8	2601.6	553.8	10.8	5.2	-881.8	17.3
	2035	163.2	2642.9	565.3	9.4	5.6	-583.3	17.5
	2040	167.6	2682.5	576.7	8.2	5.9	-282.0	17.6
	2045	171.2	2722.6	588.0	7.0	6.2	78.1	17.8
	2050	173.8	2763.8	599.7	6.0	6.5	478.3	17.9
SUR	2020	73.1	3015.5	665.2	3.5	10.7	24205.3	15.1
	2025	75.5	3055.6	677.2	3.3	11.0	26361.6	15.1
	2030	77.7	3097.7	688.7	3.0	11.3	28466.1	15.2
	2035	79.6	3133.9	698.5	3.0	11.7	30527.2	15.3
	2040	81.1	3166.5	707.5	3.0	11.9	32285.7	15.5
	2045	82.2	3198.4	716.0	3.0	12.2	34067.9	15.6
	2050	83.0	3229.7	724.3	3.0	12.5	35740.4	15.7
CEN	2020	87.4	2604.2	531.8	17.9	5.0	75.3	22.9
	2025	91.1	2650.3	543.1	16.3	5.3	64.6	23.0
	2030	94.4	2704.1	555.3	14.6	5.5	38.8	23.2
	2035	97.1	2755.5	567.0	13.1	5.7	24.7	23.3
	2040	99.4	2808.9	579.2	11.7	5.9	0.7	23.4

	2045	101.1	2864.9	592.0	10.3	6.1	-15.0	23.5
	2050	102.3	2922.5	604.9	9.2	6.4	-18.0	23.6
MEX	2020	126.2	3078.5	640.2	5.5	2.5	-22661.6	16.4
	2025	131.8	3091.0	645.2	5.3	2.8	-23654.8	16.3
	2030	136.7	3112.1	651.3	5.1	2.9	-24962.0	16.2
	2035	140.9	3132.3	657.2	5.0	3.1	-26121.3	16.1
	2040	144.3	3151.9	663.0	4.8	3.2	-27475.7	16.1
	2045	146.9	3172.3	668.8	4.7	3.4	-28483.2	16.0
	2050	148.7	3196.2	675.4	4.6	3.6	-29191.4	16.0
BRA	2020	212.4	2865.2	545.6	11.8	8.1	59287.4	14.8
	2025	219.1	2913.2	559.1	10.7	8.6	65824.8	14.8
	2030	224.5	2958.5	571.0	9.8	9.1	73188.4	14.8
	2035	228.7	2994.6	580.7	9.1	9.5	80185.7	14.8
	2040	231.6	3028.9	590.2	8.5	9.9	86502.3	14.8
	2045	233.3	3064.9	600.0	8.0	10.3	92407.1	14.7
	2050	233.7	3102.0	609.8	7.4	10.7	98617.0	14.7